NASA S-1C 2219-T37 GORE SECTION
EXPLOSIVE FORMING DEVELOPMENT PROGRAM

Summary of Phase III - Full Scale Explosive
Forming of Apex and Base Gore Segments

RYAN
AERONAUTICAL COMPANY

REPORT NO. 64B080A
5 JUNE 1964

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References:
NASA Contract No. 8-5129
Ryan Report Nos.
63B093
63B137
64B079A

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FOREWORD

This report covers the third and final phase of a Research and Development Program to determine optimum forming, tool design, and manufacturing processes for 2219-T37 gore segments for The National Aeronautics and Space Administration, George C. Marshall, Space Flight Center, Huntsville, Alabama. The program was administered for NASA by P. H. Schuerer, J. R. Williams, and L. A. Bowers.

Ryan personnel who conducted the research were P. E. Olivas, Tool Engineering, and R. A. Chase, Production.

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Approved by: K. D. Hawkins

K. D. Hawkins
Chief, Manufacturing
Technical Development

ABSTRACT

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Forming symmetrical parts, or expanding tubes or cones to precise contour, are the best applications for explosive forming. In these cases the part is self-restrained by hoop tension. Where the material involved exhibits a great deal of springback this is doubly important.

The objective of this research was to determine whether it is practical or even possible to restrain 2219-T37 aluminum by mechanical means so that a non-symmetrical part can be formed with a minimum of distortion due to springback. This program was specifically aimed at forming apex and base gores to be welded into bulkhead domes for the Saturn V tanks.

During Phase I and II of this program it was found that 2219-T37 aluminum can be held with sufficient force to elongate material .800" thick, 2 to 3 percent. It was further shown that balancing the elongation so that it is reasonably the same along each grid line aided forming. During this phase these concepts were applied to the forming of gores. Although parts formed were not close to print requirements at the time of the contract termination, sufficient progress had been made to prove that the draw at the edges of the blank can be controlled to where a part can be made to print requirement, assuming that some over-form was built into the die.

Data incidental to the program was gathered on time history and direction of shock fronts, magnitude and duration of hydraulic pressures, and metal strains in the die and tank walls, by use of strain gauges. Although not enough data was obtained to definitely establish the validity of the readings, the indication is that extensive useful Tool Engineering information can be gained by further work in this area.

Author

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RELATED REPORTS

This Research and Development program was conducted in three phases. The following list references previous reports as well as work done by North American Aviation in conjunction with this effort at the request of NASA.

I. Proposal to determine optimum forming, tool design and manufacturing processes for 2219-T37 gore segments, Ryan Report No. 63B093.

II. Summary of Phase I - Laboratory, Ryan Report No. 63B137.

Gripping Tests on 2219-T37 Plate, Ryan Metallurgical Research Report MR-63-13.

Stretch Forming 2219-T37, Ryan Metallurgical Research Report MR-63-14.

Evaluation of Explosive Forming Gripping Jaws, Ryan Metallurgical Research Report MR-63-16.

Forming Characteristics of Aluminum Alloy 2219-T37,
(1) NASA, M3FC, M-ME-1N-63-2
(2) Memo - NASA, MSFCR-ME-MMP-231-63

Explosive Forming Technical Data, Ryan Report No. 64B001.

III. Summary of Phase II - Sub-Scale

Explosive Forming, Ryan Report No. 64B079.

Explosive Forming Stress Analysis, Ryan Report No. 64B021.

Final Report, High Energy Forming of 0.5" Thick 2219-T37 Aluminum, North American Aviation Report No. V7-313211-3.

OBJECTIVES

To determine optimum forming, tool design, and manufacturing methods for 2219-T37 bulkhead gore segments for the Saturn V lox tanks.

To improve the finish contour of the apex and base gores by modifying the existing dies to increase the elongation during forming.

To show that the clamps proven during Phase II can be applied in conjunction with a draw ring to restrain and/or control slippage so that forming is improved.

To study elongation versus springback.

To gather technical data to support theories for calculating stress information and the explosive charge size for a required task.

To determine design criteria for explosive form dies.

GENERAL STATISTICS

The following approximate values are shown to give a general idea of the part sizes and forming forces involved:

APEX GORE

Blank sizes	from .297" to .80" by 160" x 169"
Area	15, 600 square inches
Perimeter	528 inches
Holding force to yield 2219-T37 aluminum	24, 288, 000 pounds
Clamping pressure to develop this holding force (minimum)	48, 376, 000 pounds
Force exerted a 15 psi vacuum	234, 000 pounds
Theoretical peak forming pressure	361, 000, 000 pounds

BASE GORE

Blank sizes	from .297" to .80" by 132" x 180"
Area	21, 600 inches
Perimeter	550 inches
Holding force to yield 2219-T37 aluminum	25, 300, 000 pounds
Clamping pressure to develop this holding force (minimum)	50, 600, 000 pounds
Force exerted by a 15 psi vacuum	324, 000 pounds
Theoretical peak forming force	500, 000, 000 pounds

GENERAL DESCRIPTION OF EQUIPMENT AND PROCEDURE

EQUIPMENT APEX DIE

Modifications included adding five stretch-press type clamps, three at the bottom and one at the center point of each side (Figure 2). The 19 C clamps mounted to a 3" x 6" hot-rolled steel draw ring (Figure 3) are actuated by 60-ton jacks. Steel picture frame shims were added to balance the elongation along each grid line from 2 to 3 percent (Figure 1). Serrated inserts 3 inches wide let into the shims increase the grip along the entire edge.

Venting to the vacuum source was increased from two No. 50 holes to nine No. 40 holes and later a 1/2 inch vacuum port was added to the previous seal groove.

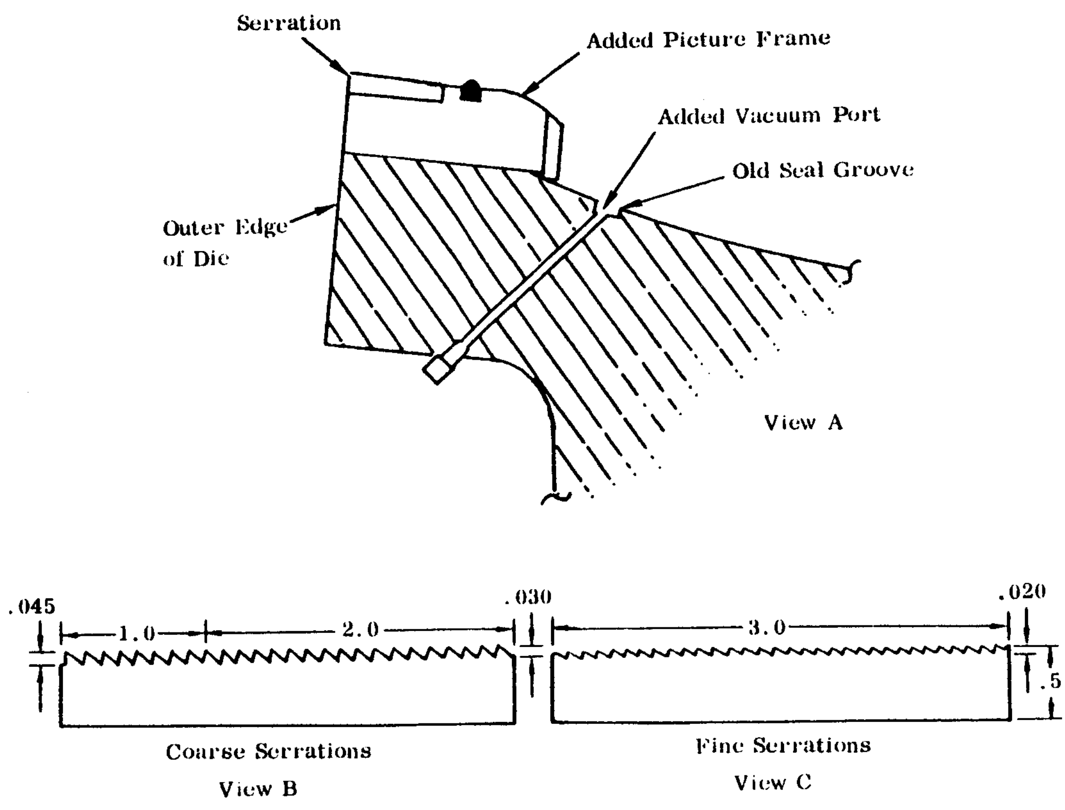

Figure 1 Typical Cross Section of Die Edge Showing Picture Frame Shim & Serrations

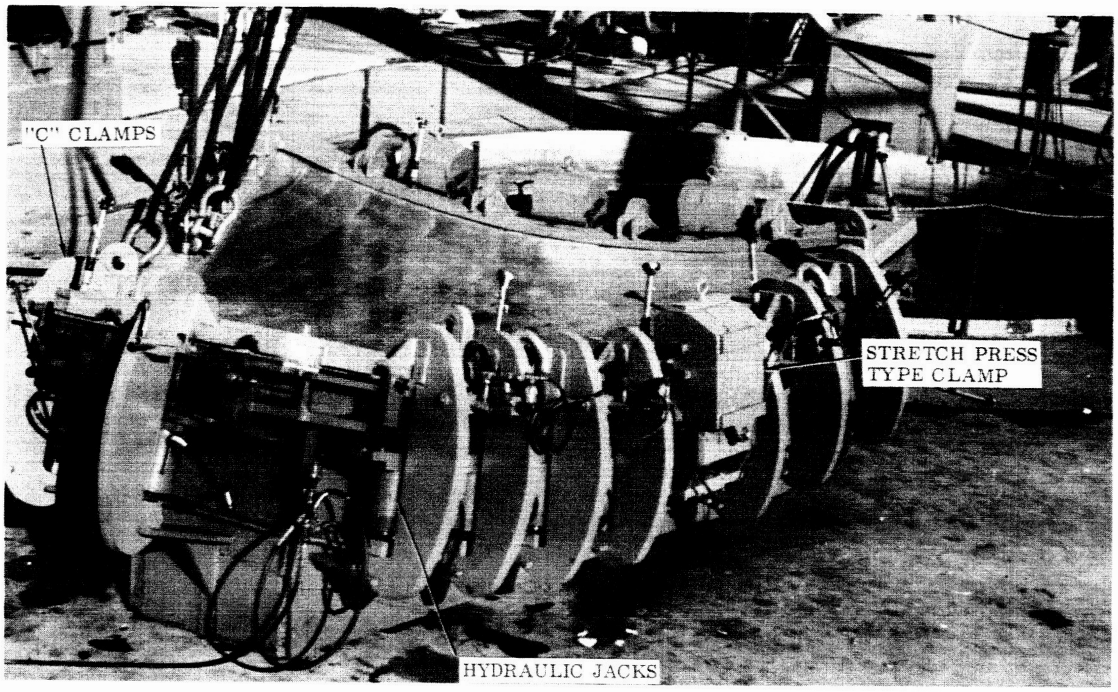

Figure 2 Modified Apex Die

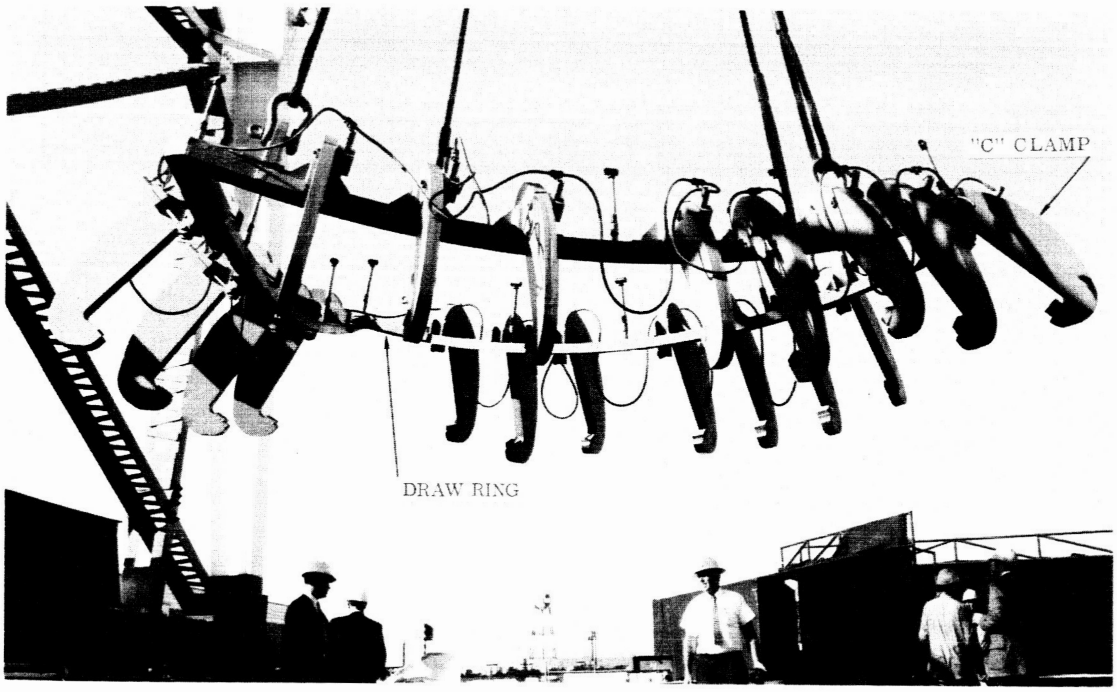

Figure 3 Draw Ring with "C" Clamps

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BASE DIE

Modifications included adding nine stretch-press type clamps, three at the base and two each to the other three sides (Figure 5). 23 C clamps were mounted on a 3" x 6" hot-rolled draw ring. Picture frame, serrations and vacuum venting were changed in the same manner as the apex die (Figure 4, item A). Stretch press clamp modification and terminology is shown in Figure 4, item B.

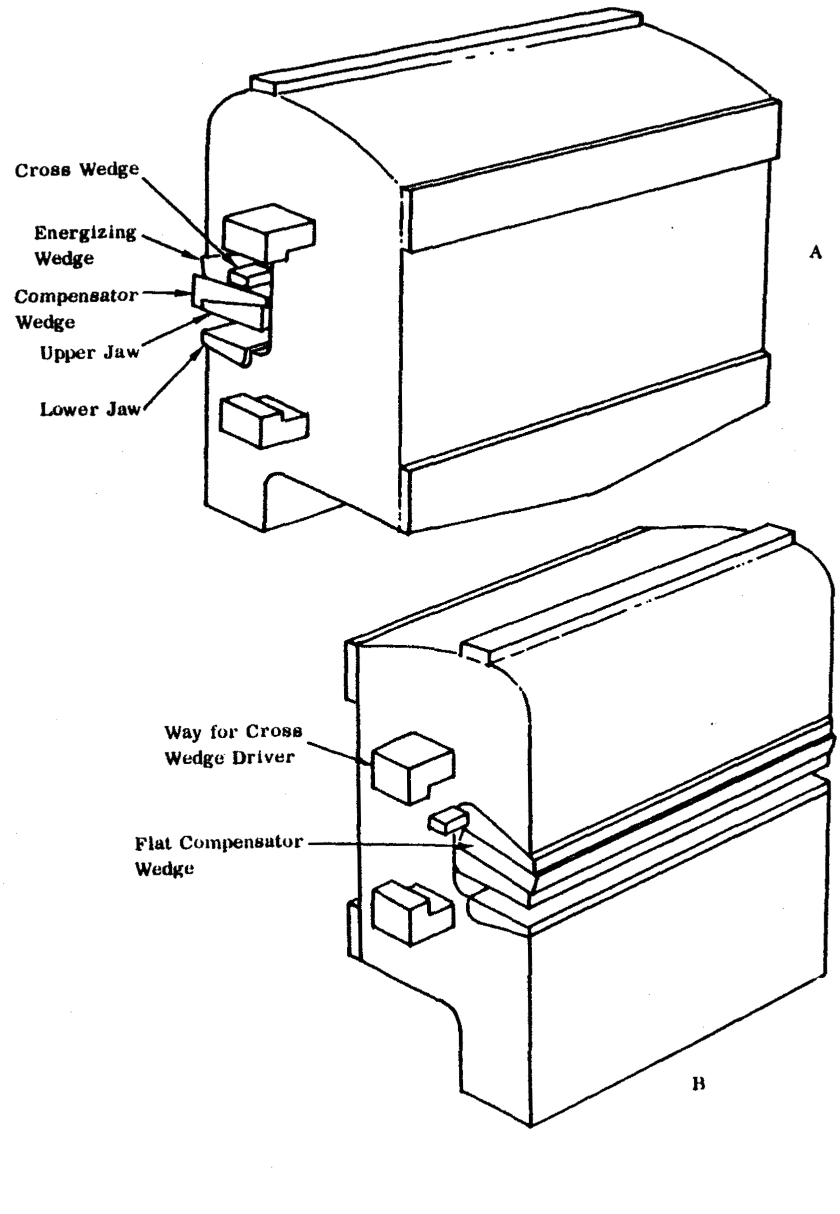


Figure 4. Stretch Press Clamp Terminology

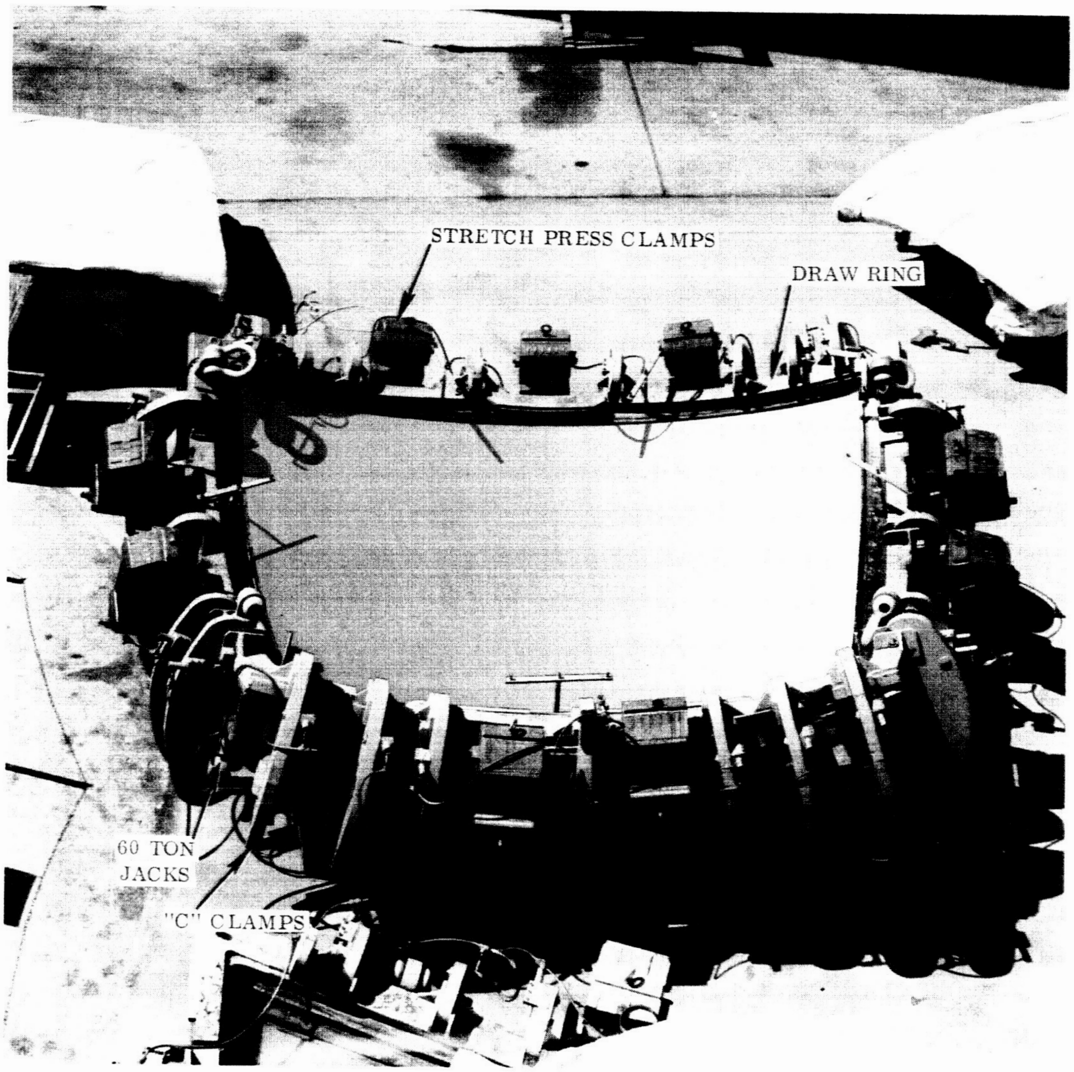


Figure 5 Base Die

Explosive - charges were made up using PETN Primacord of 100, 200, and 400 grains per foot and plastic sheet explosive Dupont EL506A-6 at 6 grains per square inch. They were mounted on 3-inch camouflage netting to maintain accurate positioning.

PROCEDURE

Material - apex material was prepared by welding extensions as shown in Figure 7. Tabs were provided with relief notches in order to reduce stress concentration at the stretch press clamps.

Base - blank configuration is shown in Figure 6. No welding was required.

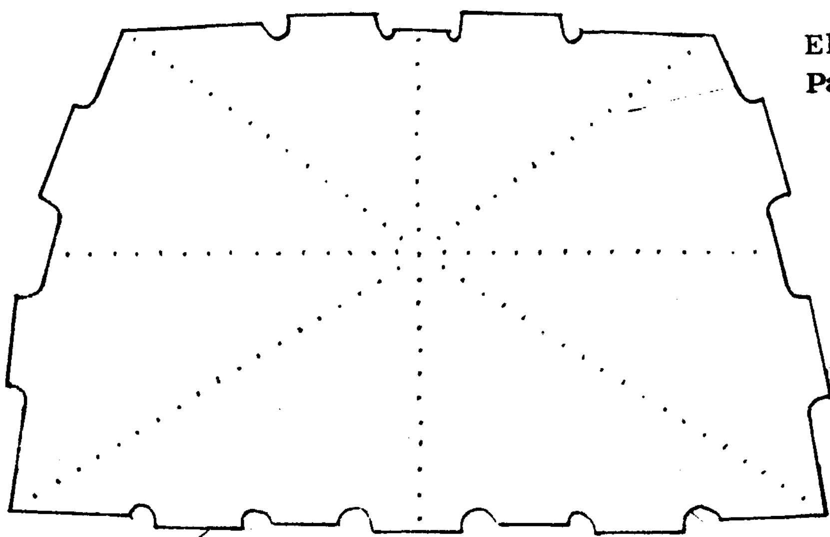


Figure 6 Base Pattern

Elongation - Marks were center-punched 5.000" apart using a jig-bored strap. The apex pattern is shown in Figure 7 while the base pattern is illustrated in Figure 6.

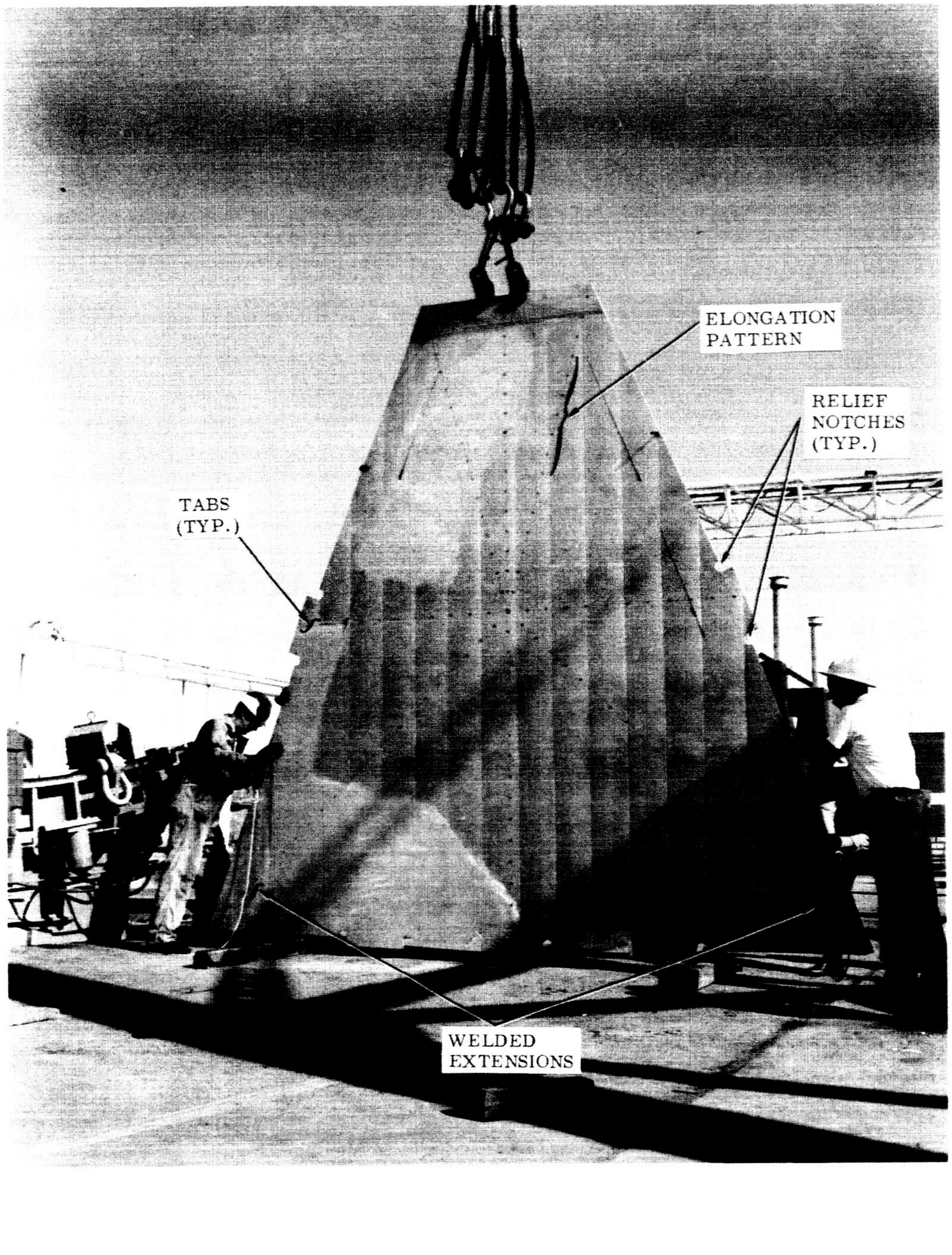


Figure 7 Apex Pattern

Loading - the blank was placed on the die and forced down by the weight of the draw ring to the edge of the die. The stretch press clamps were brought forward and the jaws energized using a 20-ton jack, leverage, and impact force to drive the cross wedge.

Charge - patterns and sizes are shown with the individual descriptions of each test. Three stages were planned on each test. The first to set the clamp jaws, the second to produce a general form close to the die, and the third to set the part to the finished contour and sharpen up detail.

Vacuum - the seal, achieved by a rubber insert in the shim, was excellent on all shots, both for the apex and the base. Readings between 29.2 and 30.2 inches of mercury were obtained.

Water Head - was 6 to 8 feet on all shots which were run in the 25-foot tank.

Clamp Pressure - on all shots was increased from 30 tons per C clamp to 60 tons after the die was in the tank just before the charge was detonated.

Instrumentation - strain gauges were mounted on the tank wall and die to insure the heavier shots planned would not endanger this equipment. It was apparent that extensive useful information could be gained from instrumentation, but since the results do not bear directly on the basic problem they are shown in the Appendix.

DATA COMPILED

Elongation - pattern was originally laid out on the inside surface so the readings on the first stages of forming could be taken without unloading. However, a comparison of inside to outside readings prove more significant. Tests No. 5, No. 6, and No. 7 were compiled in this manner.

Jaws - dimensions showing a jaw movement were taken so that energizing could be followed. The amount of side pull was also noted. The amount the material pulled in at the edge was recorded and related to the movement in the jaws. C clamp pressure was observed and recorded to insure it was not a variable.

Contour - checks using templates were made between forming stages and after the completion of forming, with part restrained in the die, in the free state untrimmed, and after trimming. One apex and one base were also checked in the inspection fixture for reference.

Charge - size and pattern were recorded to relate to forming and instrumentation data.

BRIEF DESCRIPTION OF INDIVIDUAL TESTS

TEST NO. 1

APEX BLANK NO. 1

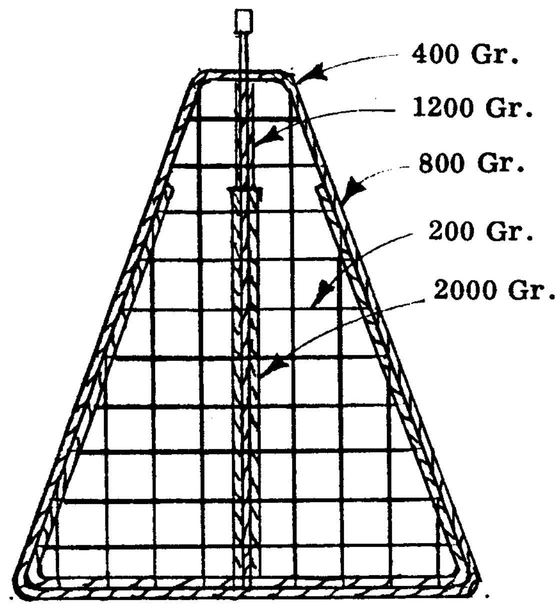
The blanks were prepared from a sheet .661" thick by 132" wide by 155" long, with two triangular tabs welded to the bottom, and a strip at the top to provide a blank 164" x 166". The Sigma welding process was used. Marks were added to the blank so the elongation could be checked (Figure 7). The periphery of the die, with the exception of the tab area, had small serrations (Figure 1, item C). The area under the extensions was left smooth in an effort to reduce the chance of weld failure. Tapered compensating wedges for .661" material were used without securing them to the upper jaw. The stretch press clamps were energized using a 20-ton jack and the draw ring was pulled down with 30-ton pressure on the C clamps. The vacuum was turned on and 29.2 inches of mercury was obtained.

Three shots were made on this blank (Figure 8). The first shot was small, 1.89 pounds to set the jaws. The second shot was a grid pattern shot using 3.75 pounds. The third shot was a grid pattern using 9.3 pounds. All shots were fired 18 inches above the work piece. The jack pressure on the C clamps was raised to 60 tons on each shot just prior to firing.

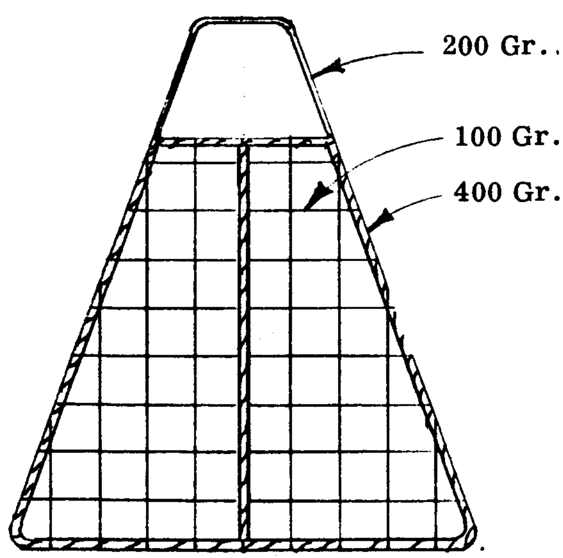
The first shot formed the part into a general bow fully energizing clamps numbers 2, 3, and 4.

The second shot took the part to the die, breaking the top weld and also leaving a flat spot near the bottom of the apex (Figure 9). The part was removed from the die and re-welded so that the third shot could be made.

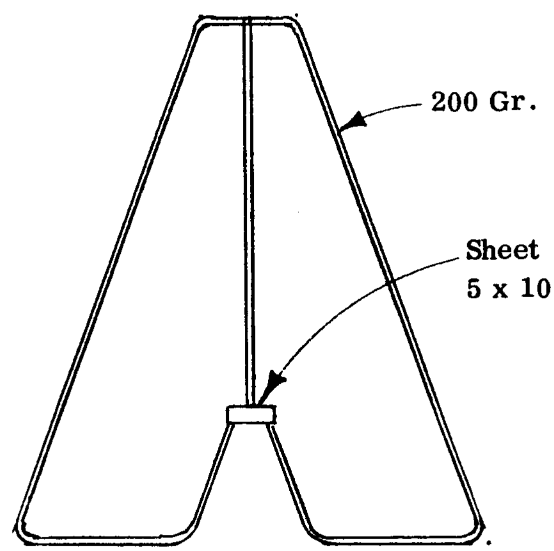
The third shot was designed with a heavy charge along the centerline to take out the flat spot. The part formed tight to the die showing the vacuum holes and the old seal groove. However, some flat remained in the part due to entrapped air caused by the vacuum holes being sealed-off by the part. Template checks showed excellent form with the exception of the flat spot while the part was held in position. However, when the part was released it sprung out of shape (Figures 10 and 12). The combination



Total Explosive 9.3 Lbs.
Shot No. 3



Total Explosive 3.75 Lbs.
Shot No. 2



Total Explosive 1.89 Lbs.
Shot No. 1

Figure 8 Blank No. 1 Explosive Charge

of weld breakage, insufficient draw ring gripping, and slippage in the clamps did not force the blank to elongate the expected amount (Figure 11).

Instrumentation - showed the stress on the tank was concentrated adjacent to the base of the die. Firing the charge with one squib at the apex seemed to cause the shock wave to sweep toward the base.

RECOMMENDATION

All welded tabs should be heliarc welded and annealed to the O-condition to reduce weld breakage. Jaws should be pinned to the material by 1/2 inch dowles passing through both jaws and the tab. The compensator wedges should be keyed to the upper jaws.

To avoid entrapping air, a 1/2 inch port should connect the vacuum line to the old seal groove (Figure 1, view A). To keep excessive shock waves from hitting the clamps at the bottom side. Two squibs should be used at the bottom corners.

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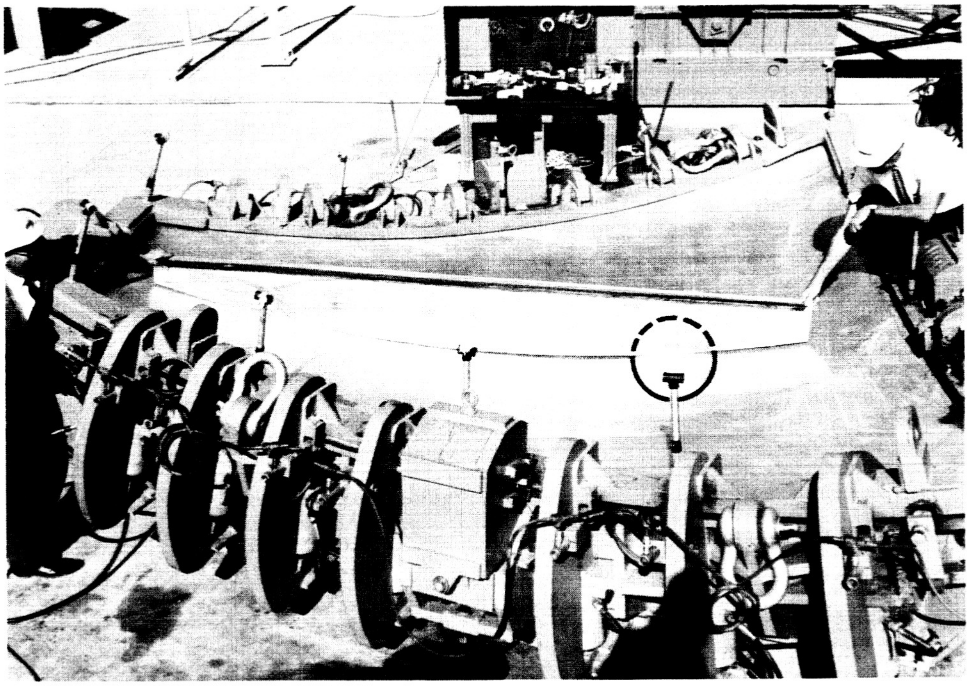

Figure 9 Formed Apex Contour Template Showing Bubble Area

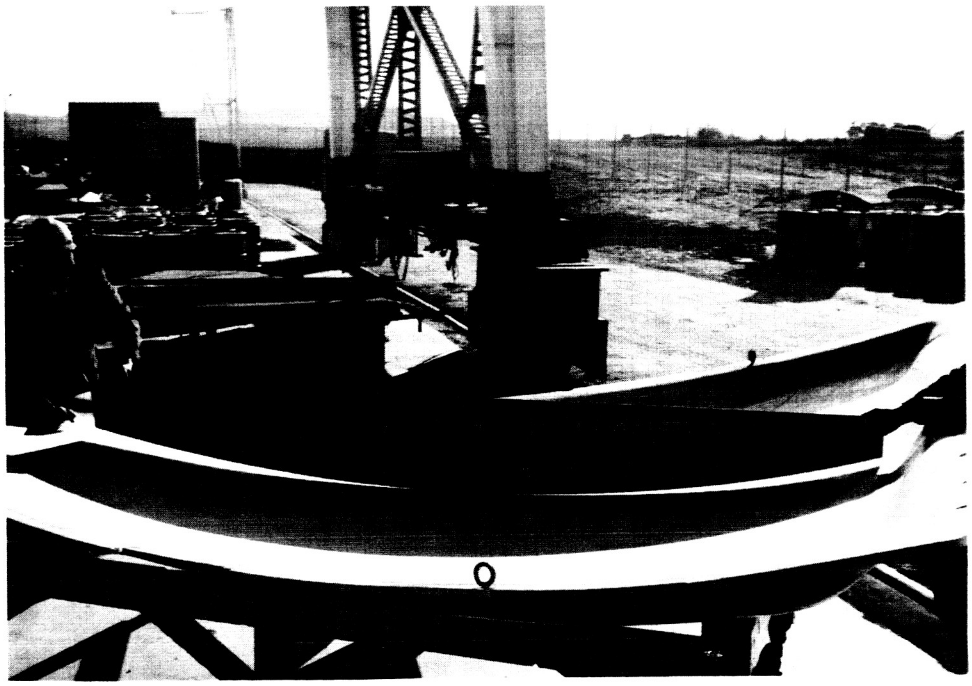

Figure 10 Formed Apex Contour Template Showing Springback in the Free State

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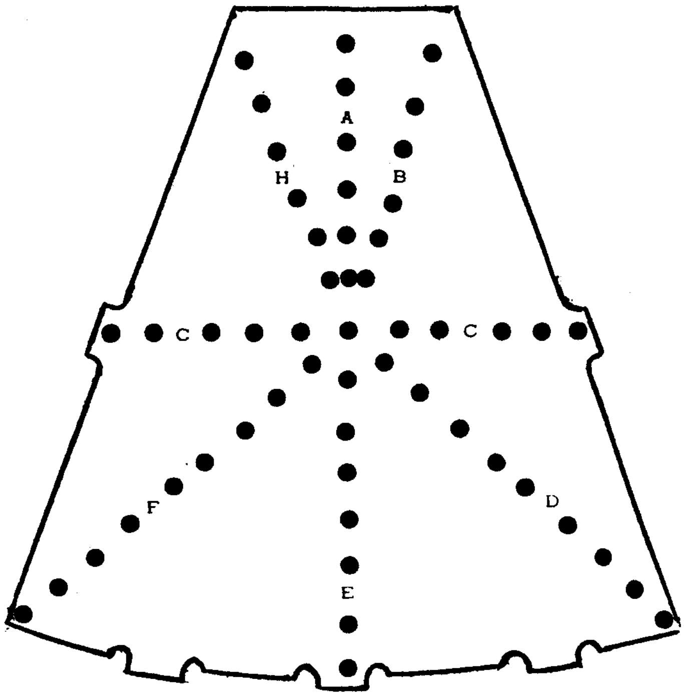
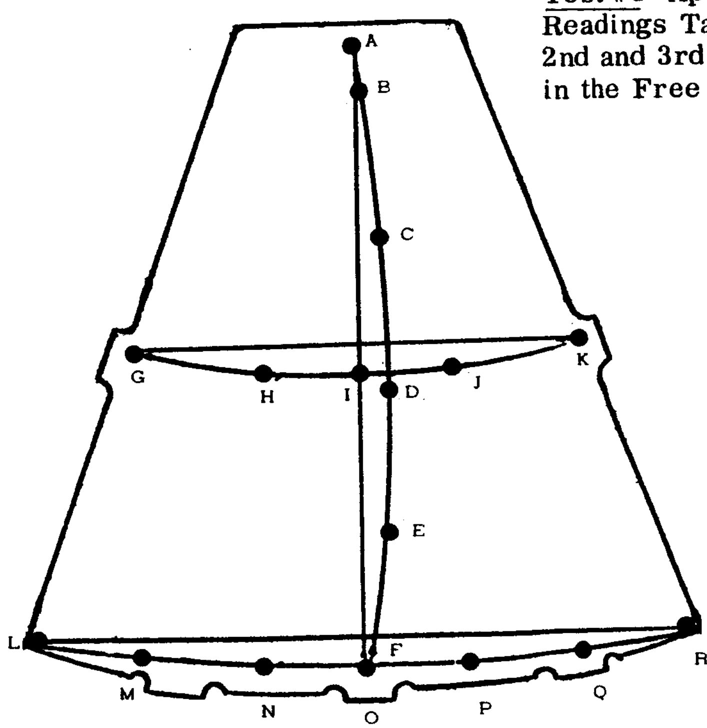


Line	Elongation 1st	2nd	3rd
A	.6 %	.62%	.68%
B	.64%	.58%	.64%
C	.1 %	.1 %	.29%
D	.39%	.49%	.5 %
E	.24%	.28%	.41%
F	.43%	.5 %	.5 %
G	.1 %	.1 %	.27%
H	.6 %	.6 %	.62%

Test #1 Apex Blank #1 - Readings Taken on Inner Surface Only After Each Shot

Figure 11 Average Percent Elongation in 5"

Test #1 Apex Blank #1 - Readings Taken After 2nd and 3rd Shot - Both in the Free State



Point	Reading 2nd	3rd
A	1.3	1.3
B	.45	.45
C	.00	.00
D	.20	.25
E	.20	.60
F	.63	1.3
G	.00	.00
H	.50	.30
I	.42	.26
J	.55	.30
K	.00	.00
L	1.10	1.10
M	.56	.56
N	.20	.17
P	.00	.00
P	.17	.17
Q	.55	.58
R	1.2	1.3

Figure 12 Template Check

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TEST NO. 2

APEX BLANK NO. 2

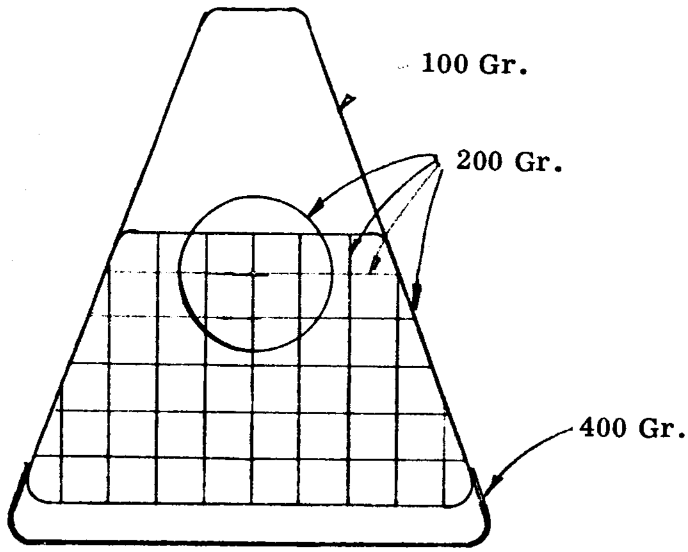
The material was prepared from a rolled blank and marked and trimmed identically to Blank No. 1 (Figure 7) except the tabs were annealed and heliarc welded. Due to the rolling, the blanks did not have as much edge distance as Blank No. 1.

The magnitude and pattern of the three shots used is shown in Figure 13. The vacuum was excellent on all of the shots, 29.2 inches of mercury, even though the weld failed in the lower left-hand corner on the second shot and had to be re-welded before the third shot. Pinning the jaws to the material effectively guaranteed the energizing of all jaws and the keys held the compensating wedges to the upper jaw. However, the cross wedge of clamp number 5 backed-off with attendant loss of holding. The tab at clamp number 1 started to fail. This failure and the backing off of the cross wedge appeared to be caused by a side motion in the clamp due to the tendency of the material to pull toward the base. The carriage of clamp number 5 broke on the second shot and had to be repaired before the final hit.

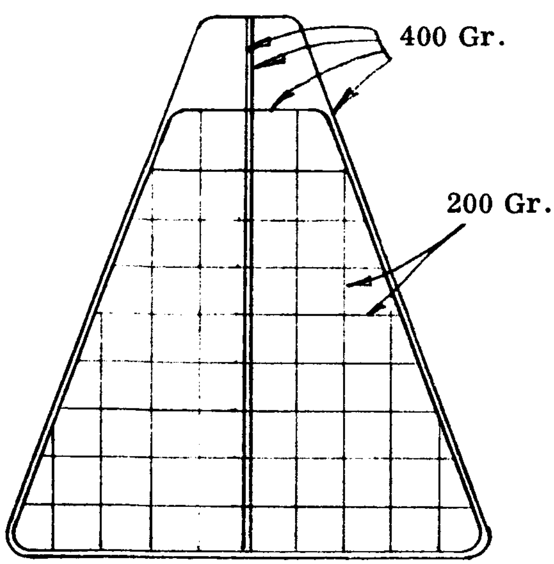
The elongation at the small end was improved from .62 percent on Blank No. 1 to .95 percent on Blank No. 2 because the extension tab weld held (Figure 14). However, the elongation elsewhere was less than 1/2 percent. Factors contributing to the low elongation were; the weld failure, minimum edge distance for the serrations to grip, the cross wedge backing off, the carriage breaking allowed the clamp to tip in, and principally the lack of sharp forming at the bottom of the part. Another shot could not be made because failure of the tab was eminent, and poor edge distance caused loss of vacuum.

RECOMMENDATIONS

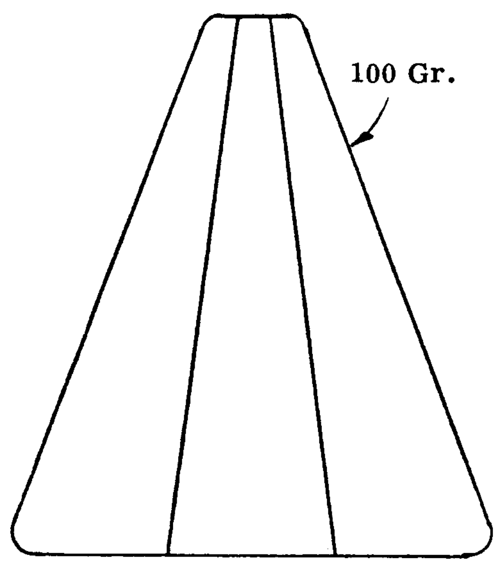
New compensating wedges required to run 1/2 inch and .297" thick material should be made so that the 1/2 inch pins tying the jaws to the blank could also pin the compensator to the upper jaw. Heavier serrations should be made for the die edge because the smaller teeth became loaded with aluminum shavings that acted like a slip sheet. The next apex blank should be made from the .500" x 11' x 16' NAA material to minimize weld tab problems. A better method should be devised to drive the cross pins tighter to prevent them from backing out.



Total Explosive 3.38 Lbs.
Shot No. 3

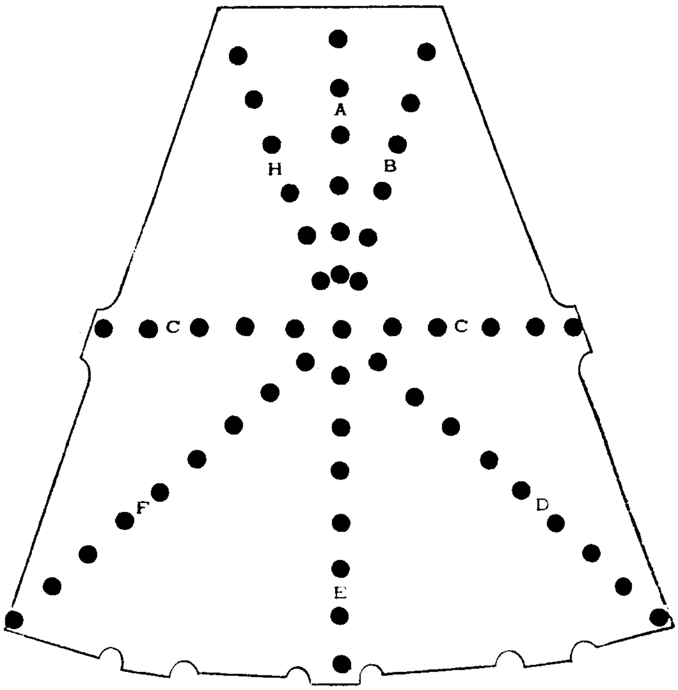


Total Explosive 3.13 Lbs.
Shot No. 2



Total Explosive .8 Lb.
Shot No. 1

Figure 13 Blank No. 2 Explosive Charge

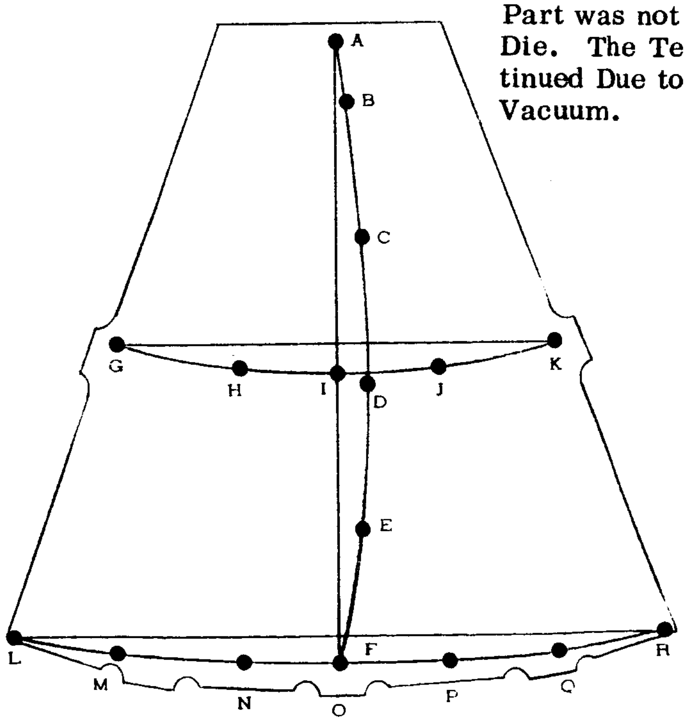


Line	Elongation
A	.58%
B	
C	.33%
D	
E	.26%
F	
G	.44%
H	

Test #2 Apex Blank #2 - Center Line Readings Only - Test Incomplete

Figure 14 Average Percent Elongation in 5"

<u>Test #2</u> Apex Blank #2 - After 2nd and 3rd Shots the Part was not down to the Die. The Test was Discontinued Due to Loss of Vacuum.



	Reading	
Point	2nd	3rd
A	1.0	.06
B	.33	.00
C	.15	.15
D	.00	.20
E	.42	.00
F	.65	.45
G	.00	.50
H	.30	.25
I	.00	.00
J	.20	.25
K	.00	.50
L	1.2	.15
M	.50	.15
N	.05	.05
O	.00	.00
P	.15	.00
Q	.80	.05
R	1.6	.40

Figure 15 Template Check

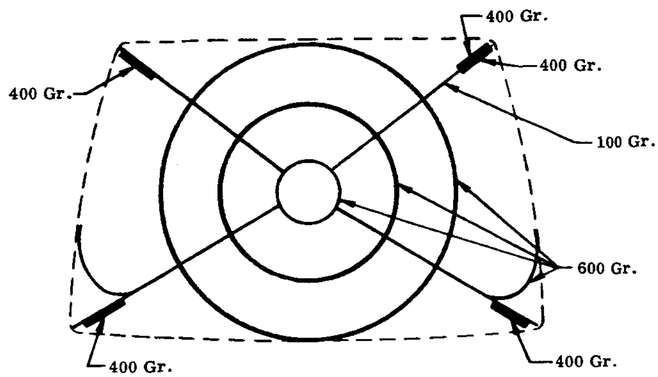
TEST NO. 3

BASE BLANK NO. 1

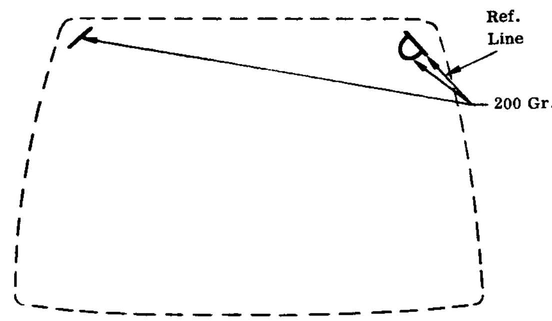
The blank was prepared from a .297" x 132" x 192" 2219-T37 flat aluminum plate trimmed and marked as shown in Figure 6. Because the edge contour of this gore is considerably more radical, fitting of the draw ring was very difficult so the test was more in the nature of a tool proofing run. During a check to see if the rubber vacuum seal was effective, the seal on the hydraulic pump failed releasing the jacks. With nothing restraining the edges, the blank buckled under a vacuum of 30.2 inches of mercury forming wrinkles at the bottom centerline and both upper corners. These wrinkles were removed and the blank re-loaded. The light first shot caused the wrinkles to re-form so two corrective local shots numbers 2 and 3 were made (Figure 16). The fourth shots broke the tabs at clamps numbers 1, 2, 7, 8, and 9, and started fractures at clamps numbers 3 and 4 causing large wrinkles to form at each clamp (Figure 17). The compensating wedge, jaws, and the material were doweled together with two 1/2 inch pins through the corners of each tab. This caused all clamps to grip (see jaw indentation, Figure 18) even though several of the compensating wedges went forward shearing the pins. The tab failure was caused by inadequate gripping by the draw ring due to poor fit of the ring, and to the fact that some of the jacks had run out of stroke. This test was inconclusive because all the load was concentrated on the tabs.

RECOMMENDATION

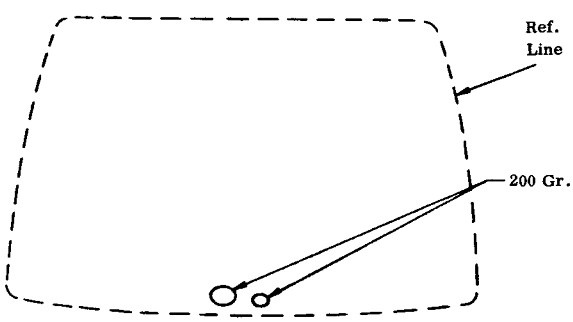
Another .297" part should be run after correcting the jacks and shimming the draw ring for a better fit.



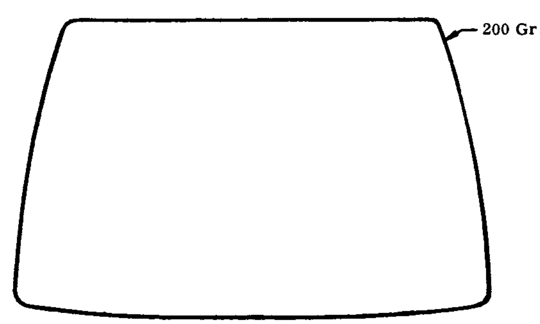
Total Exp. Chg. 5.3 Lbs.
Shot No. 4



Total Exp. Chg. .046 Lb.
Shot No. 3



Total Exp. Chg. .036 Lb.
Shot No. 2



Total Exp. Chg. 1.1 Lbs.
Shot No. 1

Figure 16 Blank No. 1

RYAN 64B080

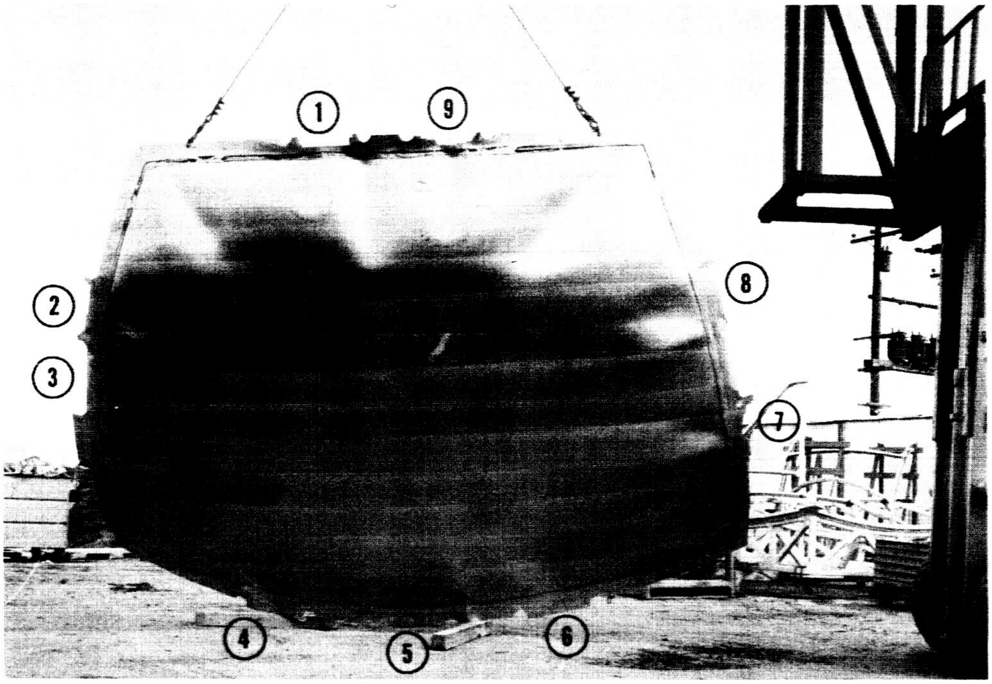


Figure 17 Wrinkle Resulting from Torn Tabs

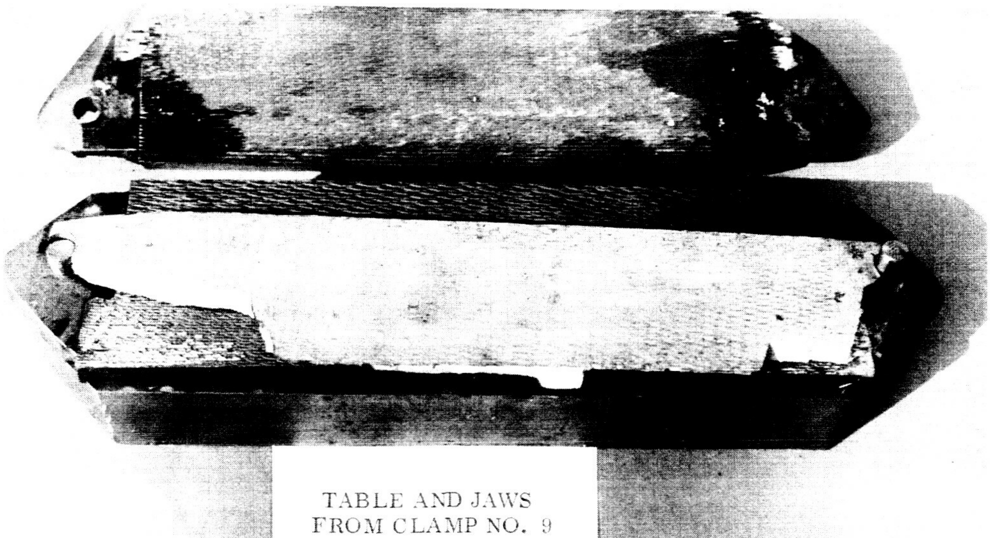


Figure 18 Closeup of Torn Tab and Jaws

TEST NO. 4

BASE BLANK NO. 2

This blank was identical to Blank No. 1, trimmed and marked in the same manner with some corrections to improve edge distance. The draw ring was shimmed so that the corrected jacks exerted as even pressure as possible, however, this still proved to be inadequate. All tabs failed on the second shot. It became apparent that cracks were propagating from the holes for the pins that doweled the jaws to the tabs (Figures 21 and 22). Four compensating wedges sheared their dowels and slid forward. Even though the tabs broke, the part exhibited fair elongation showing that the clamps were effective before the break occurred (Figure 20).

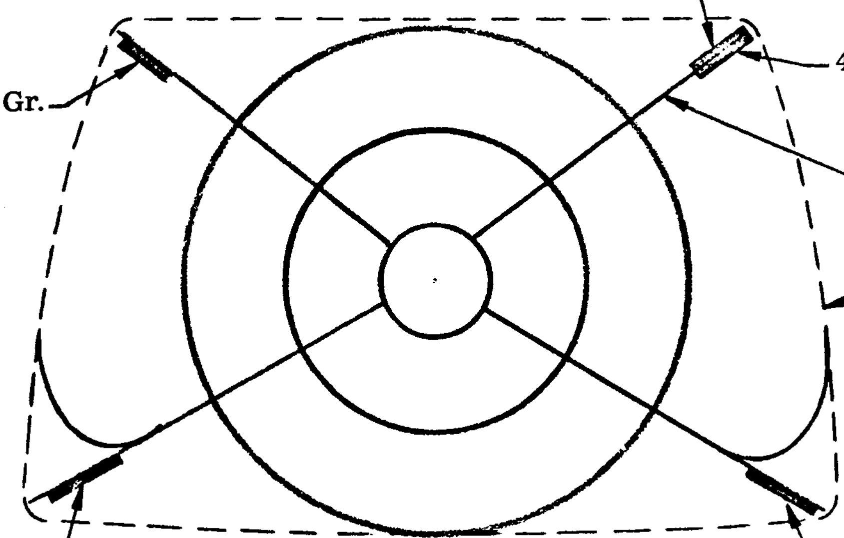
The original plan called for three stages, however, the forming was discontinued after the second shot due to tab failure and heavy wrinkles at each clamp (see Figure 19 for shot pattern).

RECOMMENDATIONS

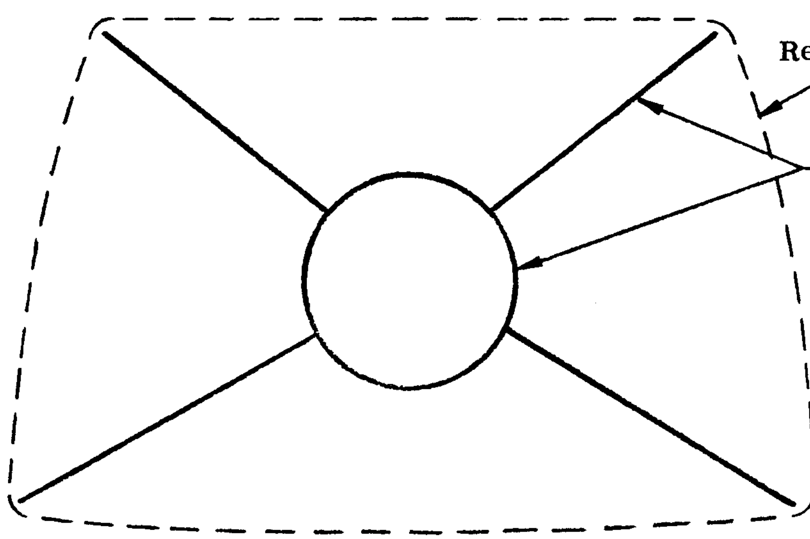
The use of pins through the tabs should be discontinued since it contributes to cracks. Instead, two cold-roll steel clips clamped against the outer edge of the jaws by Allen screws tapped into the edge of the tab should be used to assure the jaws moving in with material (Figure 23).

Coarser serrations should replace the fine ones around the edge of the die to improve the draw ring grip. A better job of shimming is also necessary since a poor fit is the main factor causing tab failure.

A heavier blank should be tried since it will be less sensitive to local overloading.



Total Exp. Chg. 5.3 Lbs.
Shot No. 2



Total Exp. Chg. .33 Lb.
Shot No. 1

Figure 19 Shot Patterns Blank No. 2

Upper figures were taken along the inner surface - lower figures along the outer surface.

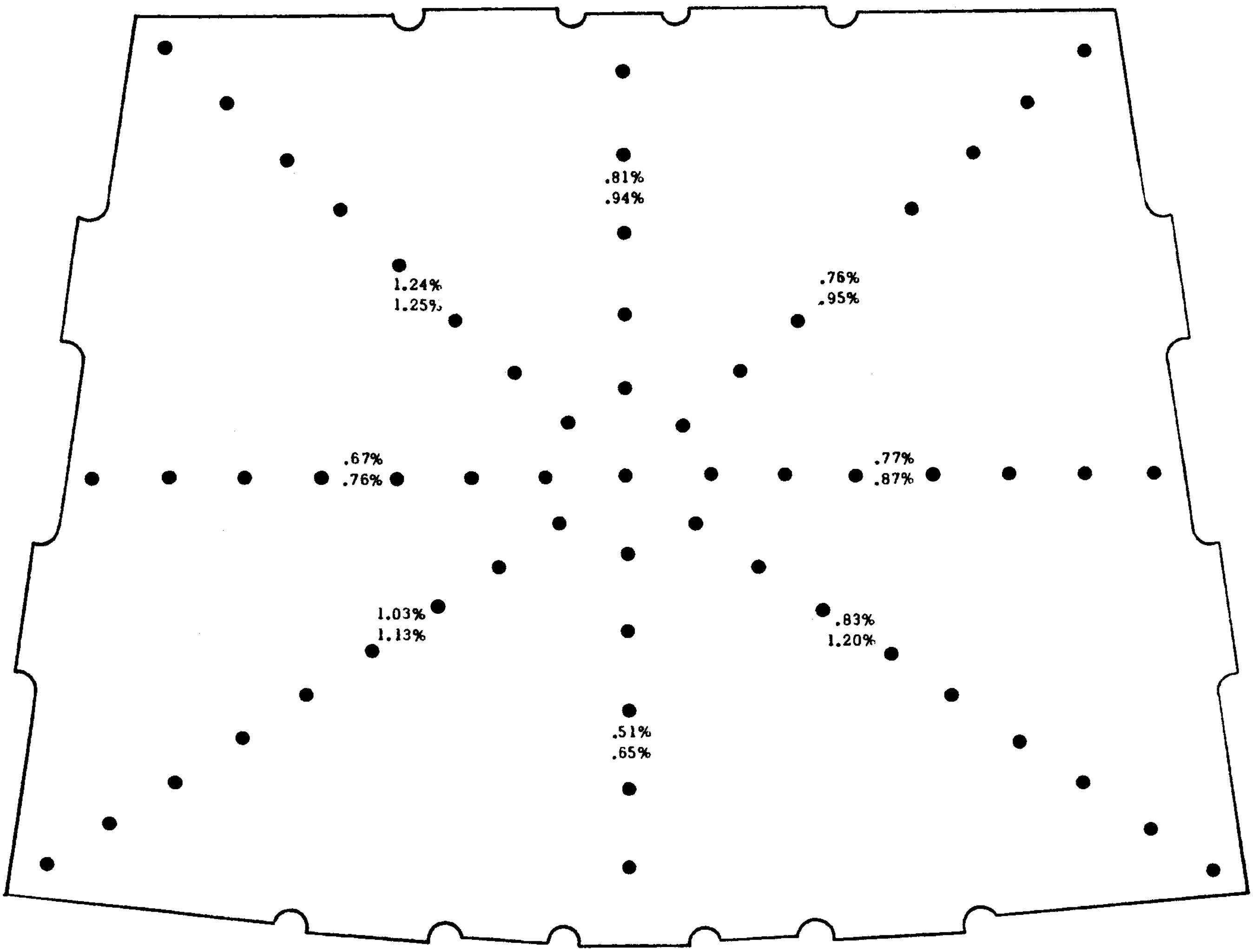


Figure 20 Test No. 5 - Base Blank No. 2 - Average Elongation in 5"

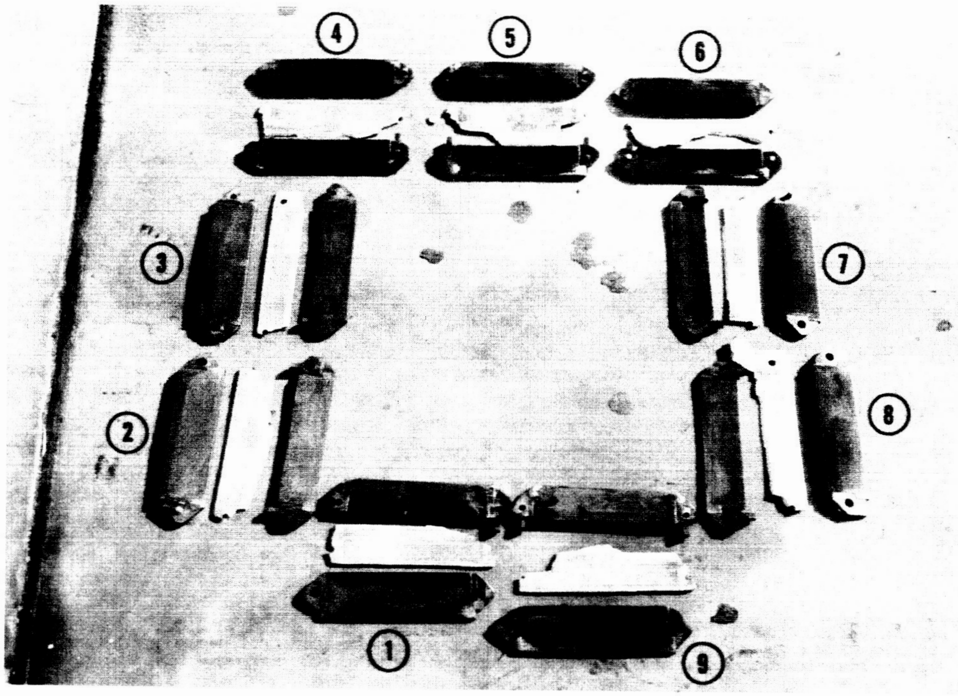


Figure 21 Base Blank No. 2 Showing Tab Cracks Propagating From Holes

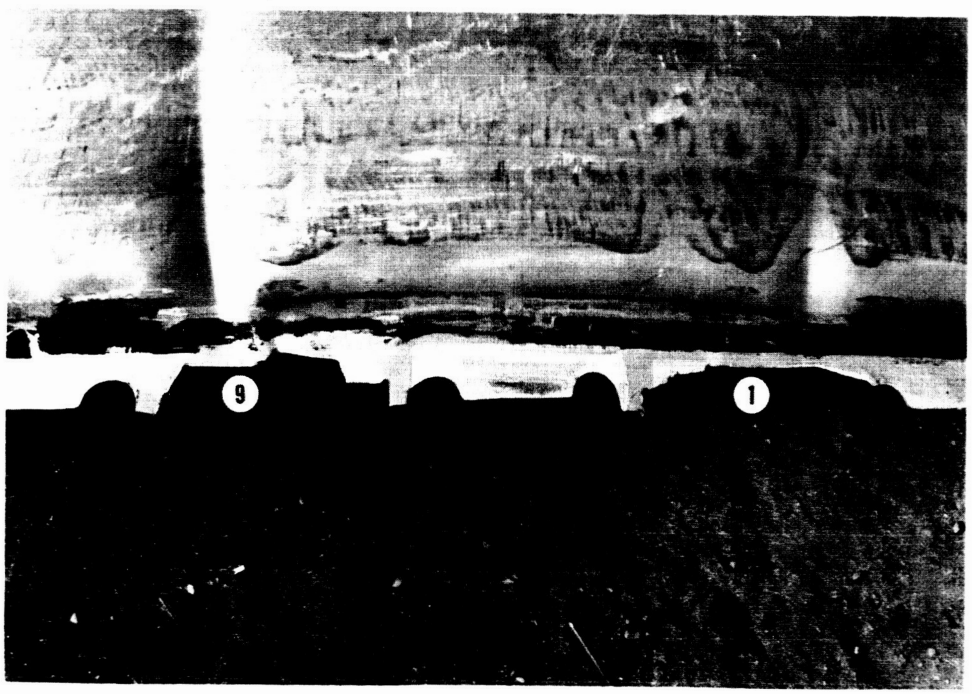


Figure 22 Base Blank No. 2 Showing Area From Which Tabs 1 and 9 Were Torn

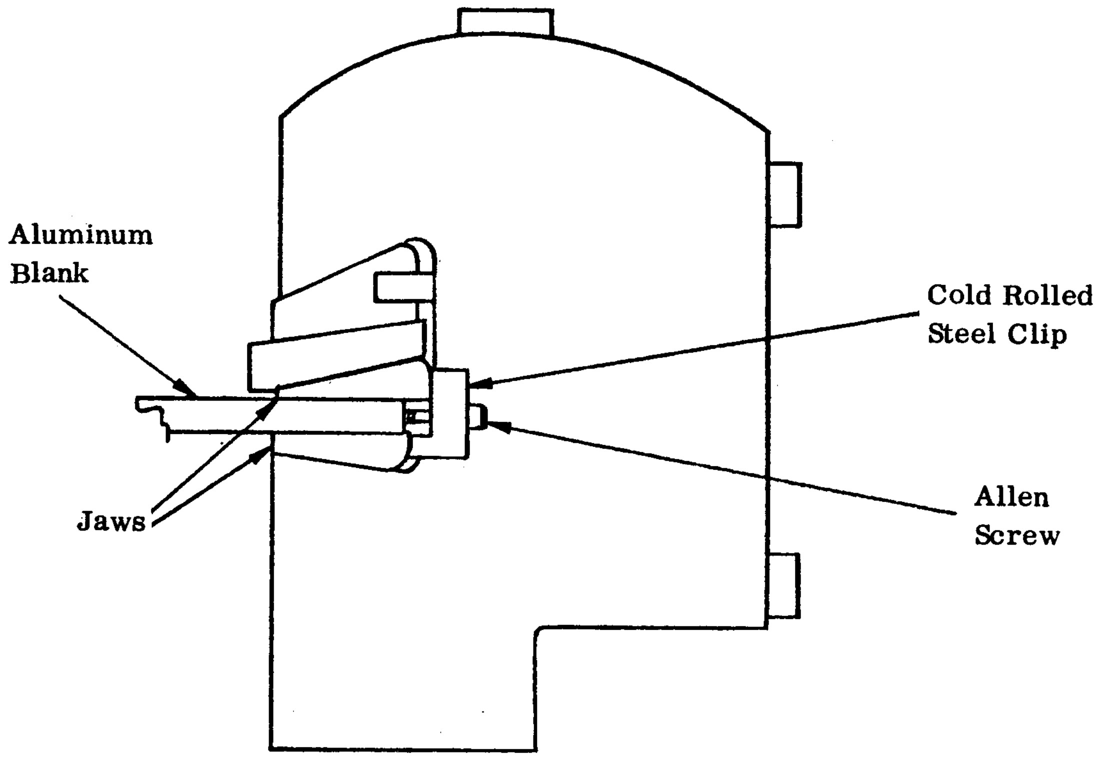


Figure 23 Clip Screw Tapped Into Block

TEST NO. 5

APEX BLANK NO. 3

The blank was prepared from a .500" x 144" x 192" flat plate of 2219-T37 aluminum. It was trimmed and marked to the same pattern as Blanks No. 1 and 2 (Figure 7) with corrections to provide adequate edge distance and jaw grip. The only extensions required on the larger sheet were small annealed triangles heliarc welded at the bottom corners.

The part was formed in three stages, the pattern and size of each shot is shown in Figure 24.

The jack pressure on the draw ring was 60 tons on all shots. The small serrations were replaced by coarser ones (Figure 1, view C). The welds were protected from overloading by slip sheets under the triangular tabs.

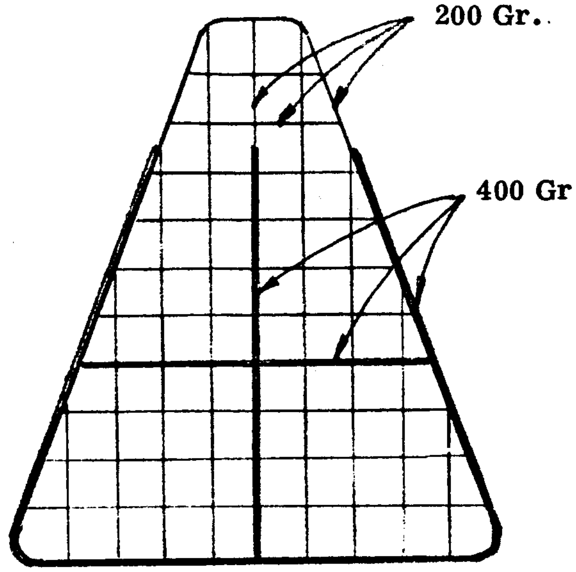
One-quarter inch Allen bolts tapped into the edge of the sheet were used to assure the gripping of the jaws (Figure 23). The compensating wedge on clamp number 1 sheared the two 1/2 inch pins doweling it to the upper jaw and the cross wedge clamps numbers 1 and 5 backed-out reducing shot gripping efficiency. Gripping of clamps numbers 2, 3, and 4 were completely successful.

The forming was discontinued at the end of the third shot due to a crack in front of clamp number 1 caused by too sharp a radius on the picture frame. The contour was good except for a flat spot in the center between clamps numbers 1 and 5, and along the bottom edge where the Ogee radii were not well defined. Because this area in front of the bottom clamps was not down to the die the elongation could have been increased by another shot. However, removal from the die for welding would have been necessary, therefore, more was to be learned from a new blank. The blank straightened out along the bottom edge when removed from the die. This shows the need for more holding at the corners and, therefore, the need for a wider blank.

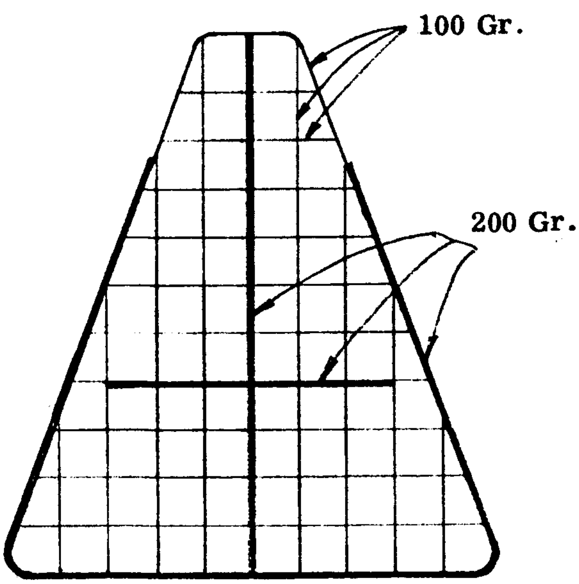
RECOMMENDATIONS

Despite the short distance that jaws travel they cause the compensating wedge to have more inertia than can be restrained by practical means. Therefore, the compensating wedge should be re-designed to remain stationary. This has the added advantage of reducing the weight the pre-energizing grip on the tabs has to move (Figure 4, view B for re-design). The Allen bolts and clips were very successful, causing no tab failure, however, for added safety the bolt diameter should be increased to

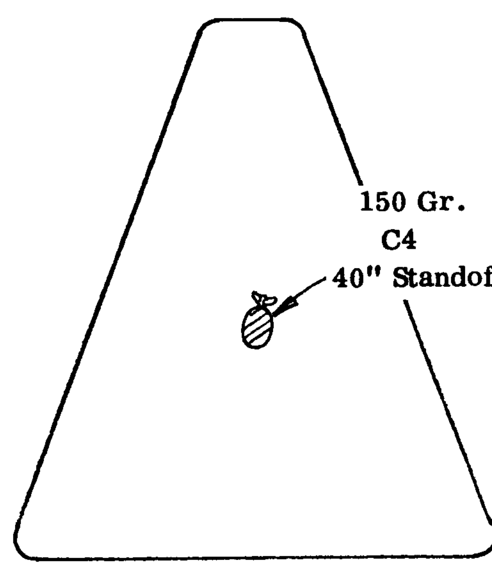
5/16 inches. The sharp radius that caused the break should be reworked. The excessive pull at the apex end indicates the need for more holding force. Two jacks should be added to accomplish this.



Total Explosive 4.3 Lbs.
Shot No. 3

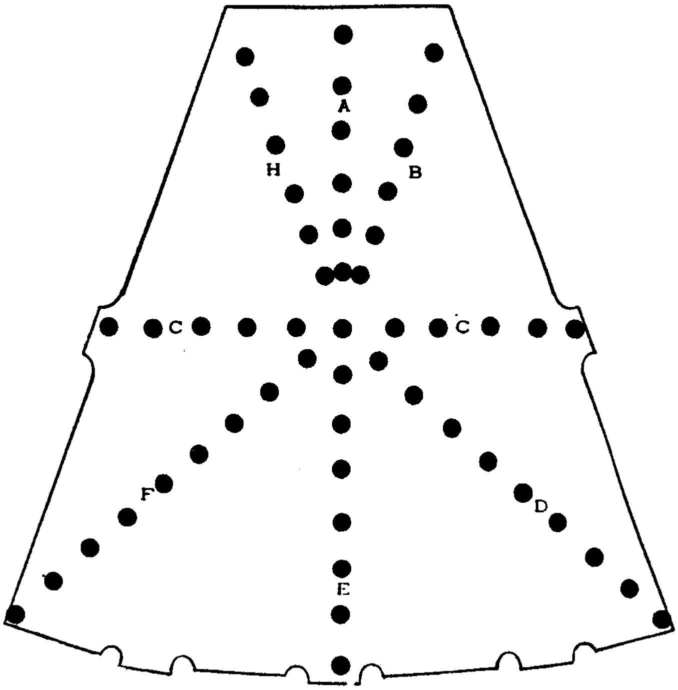


Total Explosive 2.55 Lbs.
Shot No. 2



Total Explosive .4 Lb.
Shot No. 1

Figure 24 Blank No. 3 Explosive Charge

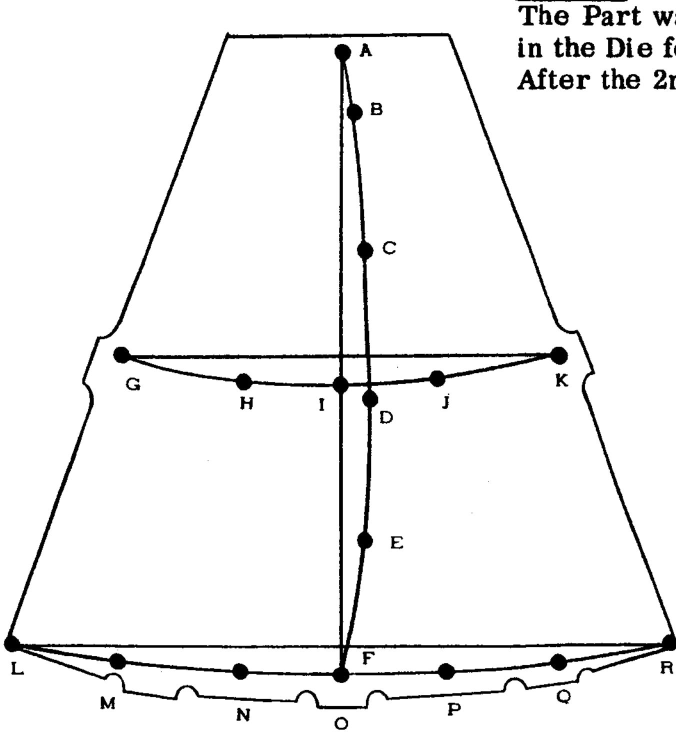


Line	Elongation	
	Inner	Outer
A	.81%	1.11%
B	.96%	1.01%
C	.1 %	.3 %
D	.5 %	.74%
E	.71%	.97%
F	.6 %	.7 %
G	.48%	.86%
H	.69%	.86%

Test #5 Apex Blank #3 - Readings Taken After the 3rd Shot

Figure 25 Average Percent Elongation in 5"

Test #5 Apex Blank #3 - The Part was Restrained in the Die for Both Checks After the 2nd and 3rd Shots



Point	Reading	
	2nd	3rd
A	.45	.13
B	.32	.06
C	.00	.00
D	.25	.00
E	.50	.20
F	.00	.00
G	.08	.02
H	.22	.05
I	.00	.00
J	.22	.05
K	.00	.20
L	1.5	.37
M	.90	.20
N	.20	.05
O	.00	.00
P	.21	.05
Q	.90	.20
R	1.5	.37

Figure 26 Template Check

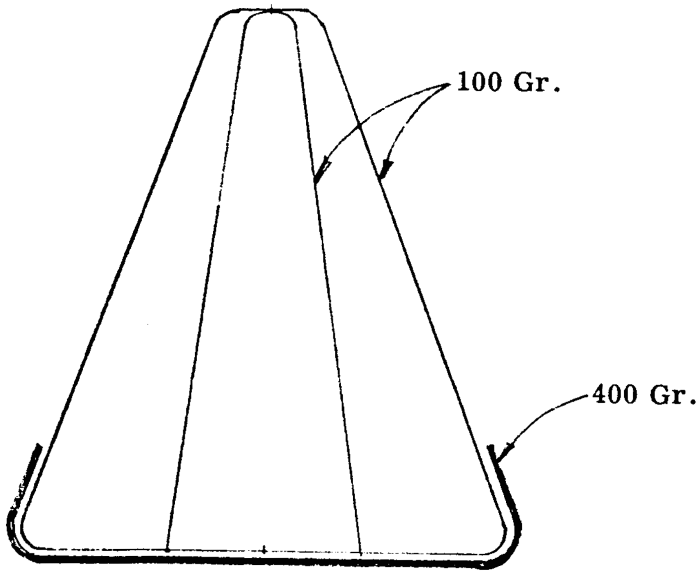
TEST NO. 6

APEX BLANK NO. 4

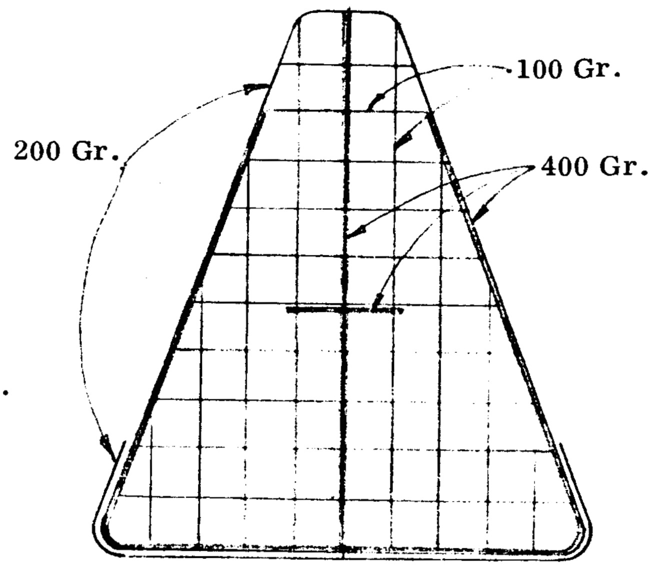
A blank identical to apex Blank No. 3 was prepared from .500" x 144" x 192" material. When loaded into the die it had good edge distance and the tabs engaged 100 percent of the area of the jaws. Two 20-ton jacks were added to the small end but proved inadequate, although they reduced the the amount the edge of the blank pulled in. Cold-roll steel clips attached to the tabs by Allen bolts tapped into the edge of the material were used as a positive means of energizing the jaws. All clamps held except the cross wedge on clamp number 5 backed-out even though it was driven in with the impact tool. This did not result in much jaw movement or loss of elongation. Jaws of clamps numbers 1 and 5 slid side-ways toward the bottom and clamps numbers 2 and 4 toward the centerline. This side motion indicates the need for increased holdings at the bottom corners and the apex.

Contour was checked by templates in the die after the third and fourth shot and in the unrestrained condition before and after trimming (Figure 29). The part straightened out along the bottom and at the center points on each side. Again this emphasizes the need for increased holding force at the bottom corners and at the apex.

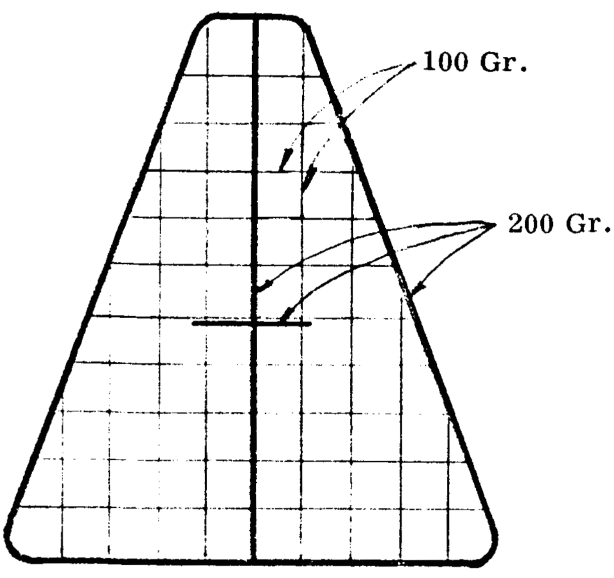
A full set of elongation readings (Figure 38) on this test is shown to illustrate the data that was recorded from which the average elongation charts (Figure 28) were compiled.



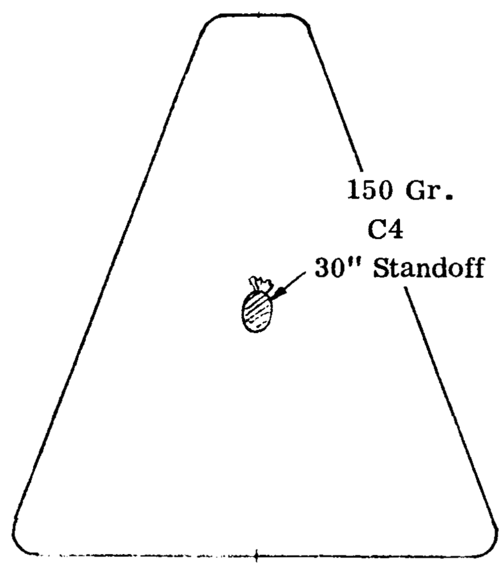
Total Explosive 1.7 Lbs.
Shot No. 4



Total Explosive 4 Lbs.
Shot No. 3

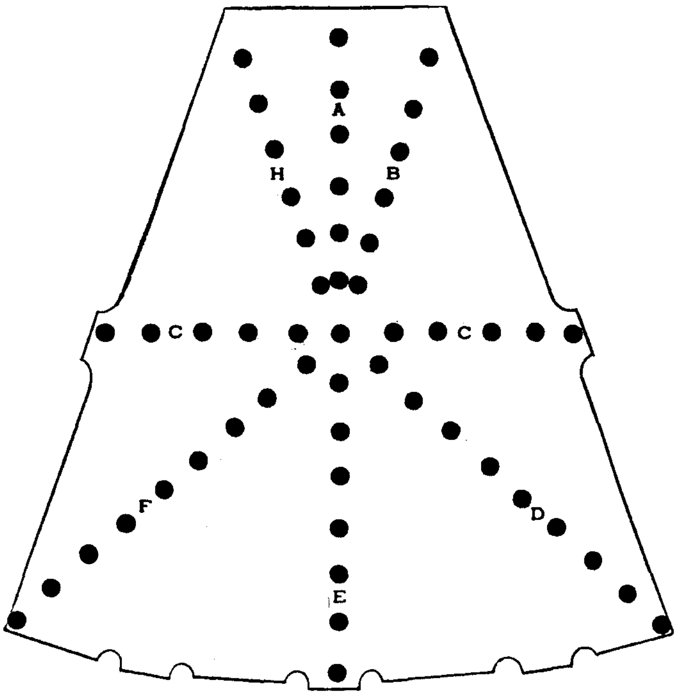


Total Explosive 2.62 Lbs.
Shot No. 2



Total Explosive .4 Lb.
Shot No. 1

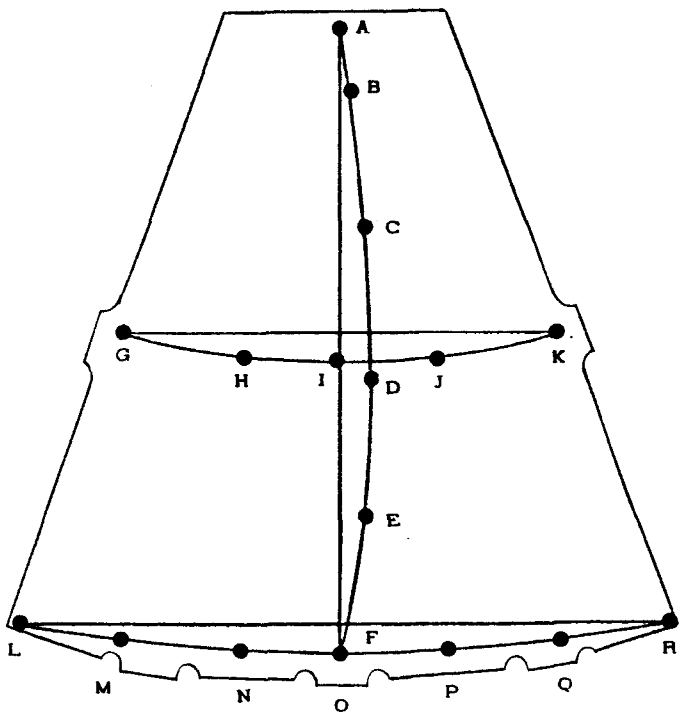
Figure 27 Blank No. 4 Explosive Charge



ELONGATION		
LINE	INNER	OUTER
A	.97%	1.32%
B	.93%	1.13%
C	.62%	1.22%
D	.59%	.97%
E	.74%	1.32%
F	.67%	.91%
G	.68%	1.15%
H	1.08%	1.4 %

Test No. 6 Apex Blank No. 4 Readings Taken on Inside and Outside of the Sheet After the Final Shot

Figure 28 Average Percent Elongation in 5"



	READING		
POINT	R	F	T
A	.13	.30	.00
B	.06	.70	1.2
C	.00	.00	1.5
D	.00	.40	1.7
E	.10	.50	2.1
F	.00	.00	.00
G	.00	.00	.00
H	.20	.28	.25
I	.13	.25	.25
J	.14	.28	.25
K	.00	.00	.00
L	.30	1.5	3.9
M	.10	.20	1.9
N	.00	.15	.42
O	.04	.00	.00
P	.00	.15	.40
Q	.15	.67	2.0
R	.38	1.4	3.9

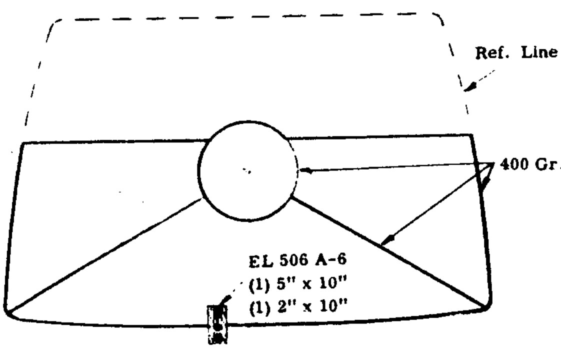
Test No. 6 Apex Blank No. 4
R = Restrained in Die
F = Free
T = Trimmed

Figure 29 Template Check

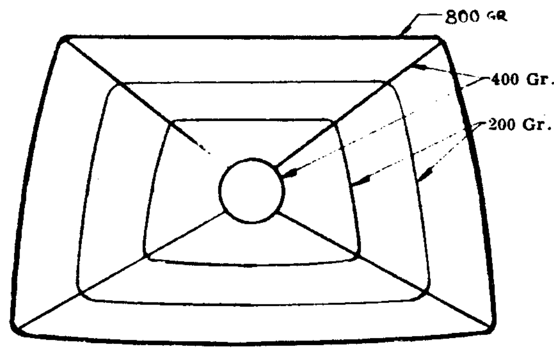
TEST NO. 7

BASE BLANK NO. 3

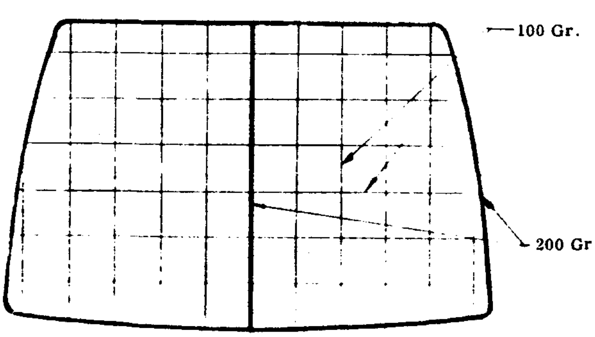
A rolled sheet of 2219-T37 aluminum .661" x 132" x 192" was used for Blank No. 3. Three forming stages were originally planned to which two post forming shots were added (Figures 30 and 31). Flat compensating plates were used and 3/8 inch Allen bolts clamped the clips to the jaws. Coarse serrations were used and the draw ring carefully shimmed. Jack pressure was up to 60 tons and the vacuum 29.8 inches of mercury. The first charge of .28 Primacord set the clamps and the second shot gave the blank a general form. The third shot broke the tabs at clamps numbers 4, 5, and 6, but did not lose vacuum. The part had a flat area in the center and was not tight to the die along the bottom side next to the broken tabs. It was decided to bottom the part against the die and sharpen the contour at the bottom so shots numbers 4 and 5 were made. The part was checked in the die, in an unrestrained condition and after final trim. It flattened out across the blank causing an apparent over-form from top to bottom (Figures 33, 34 and 35). Elongation was exceptionally high considering the tabs failed (Figures 32 and 39). The clamps and clips worked well except that the cross wedge on clamp number 6 backed-out. The flat compensating plates did not move and all clamps unloaded with reasonable ease.



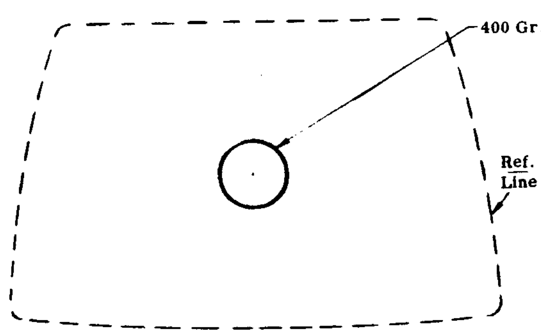
Total Exp. Chg. 3 Lbs.
Shot No. 4



Total Exp. Chg. 7.5 Lbs.
Shot No. 3

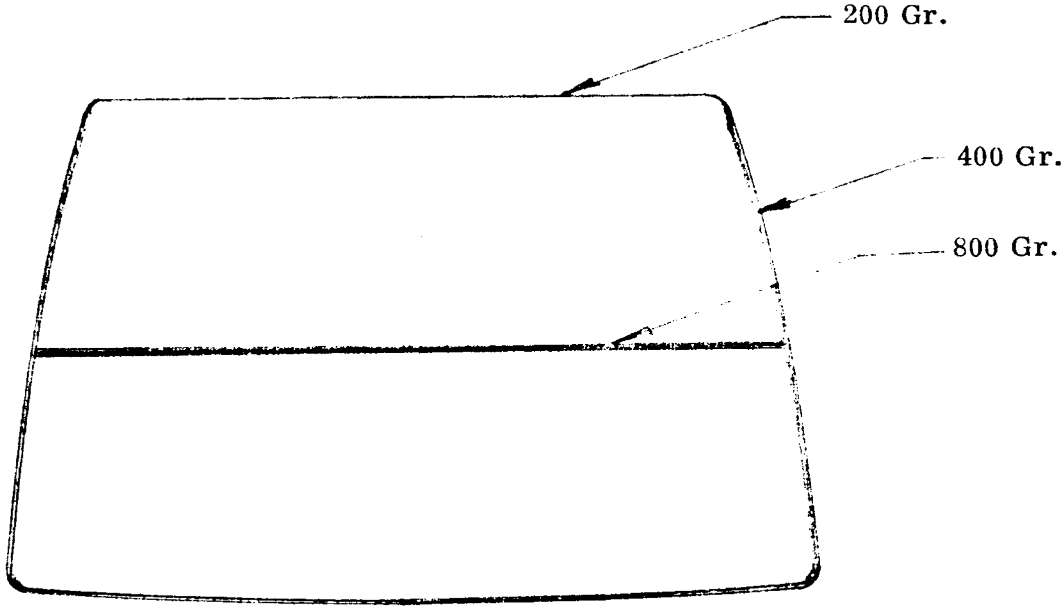


Total Exp. Chg. 3.8 Lbs.
Shot No. 2



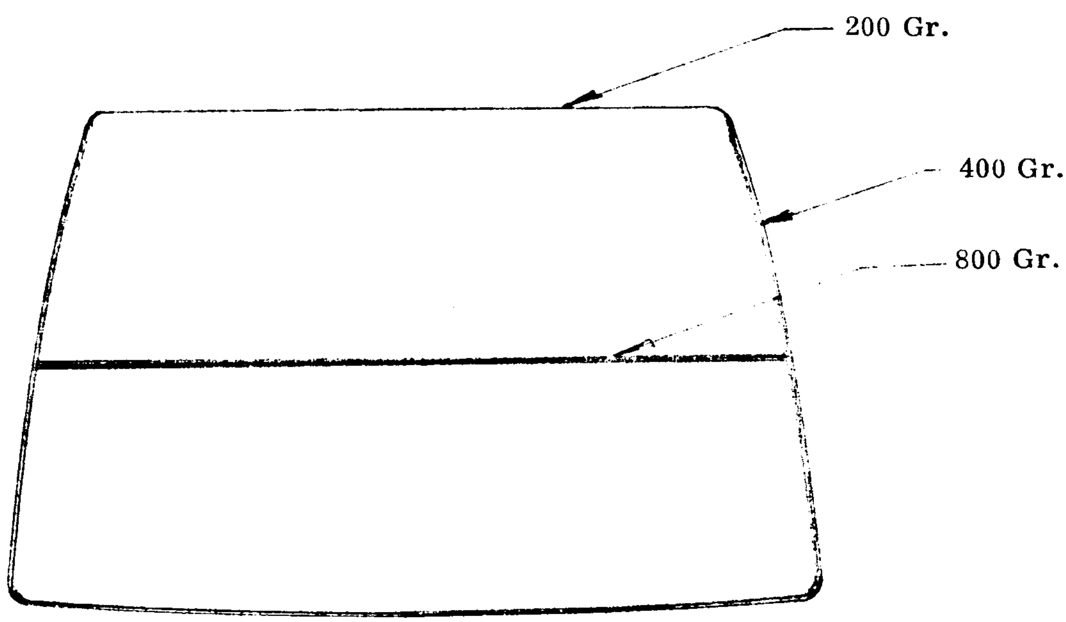
Total Exp. Chg. .28 Lbs.
Shot No. 1

Figure 30 Blank No. 3



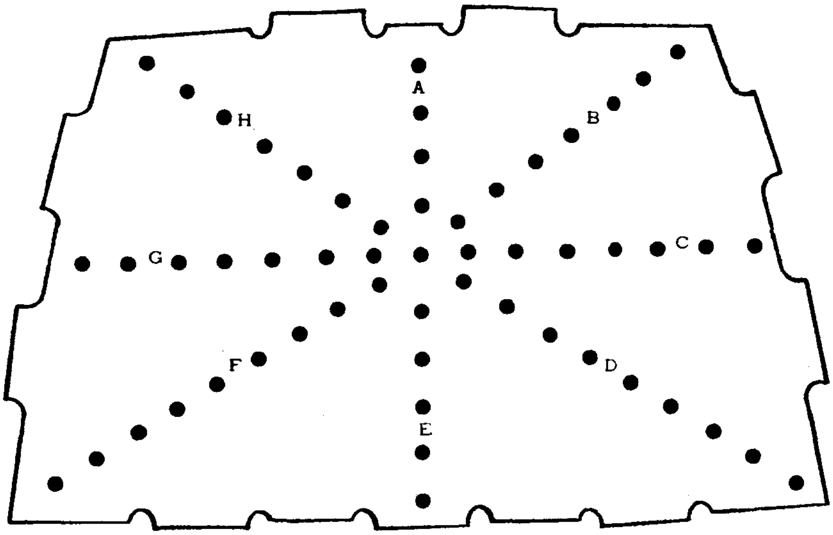
Total Exp. Chg. 2.75 Lbs.
Shot No. 5

Figure 31 Blank No. 3



Total Exp. Chg. 2.75 Lbs.
Shot No. 5

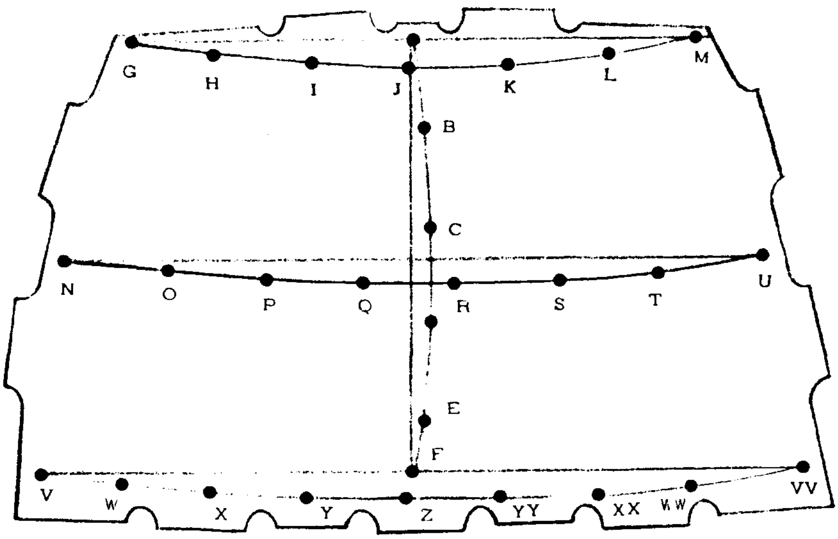
Figure 31 Blank No. 3



Line	Elongation	
	Inner	Outer
A	.66%	1.12%
B		1.27%
C	1.22%	1.45%
D		1.13%
E	.55%	1.02%
F		1.27%
G	.97%	1.26%
H		1.13%

Test #7 Base Blank #3 - Readings Taken After the 5th Shot

Figure 32 Average Percent Elongation in 5"



Test #7 Base Blank #3 - Readings After 4th and 5th Shot, in Free State and Trimmed

Point	Reading			
	4th	5th	F	T
A	1.00	.70	.00	.00
B	.05	.12	.17	.20
C	.20	.07	.50	2.30
D	.08	.17	.42	2.05
E	.00	.30	.12	.70
F	.00	.35	.00	.00
G	.00	.00	.85	1.25
H	.07	1.20	.37	.65

Point	Reading			
	4th	5th	F	T
I	.15	.15	.12	.07
J	.00	.14	.00	.00
K	.12	.10	.27	.55
L	.03	.03	.40	1.10
M	.00	.00	.85	1.70
N	.11	.80	.29	4.00
O	.40	.60	1.60	1.80
P	.04	.10	.65	.50
Q	.05	.00	.10	.00
R	.05	.15	.15	.25
S	.24	.80	.65	1.10
T	.50	.42	1.40	2.60
U	.75	.70	2.50	4.30
V	.00	.00	2.00	5.00
W	.30	.27	1.50	3.80
X	.27	.22	.72	1.85
Y	.20	.15	.18	.55
Z	.15	.15	.00	.00
YY	.12	.15	.17	.40
XX	.27	.25	.85	1.75
WW	.22	.22	1.70	3.40
VV	.00	.00	2.38	4.50

Figure 33 Template Check

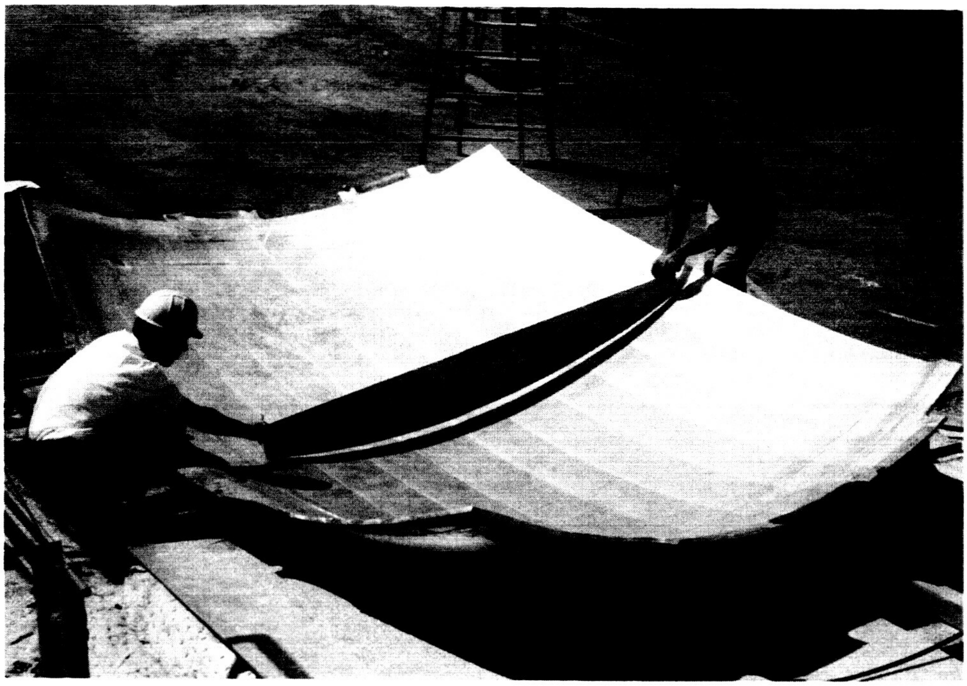


Figure 34 Test No. 7 Base Blank No. 3 Untrimmed

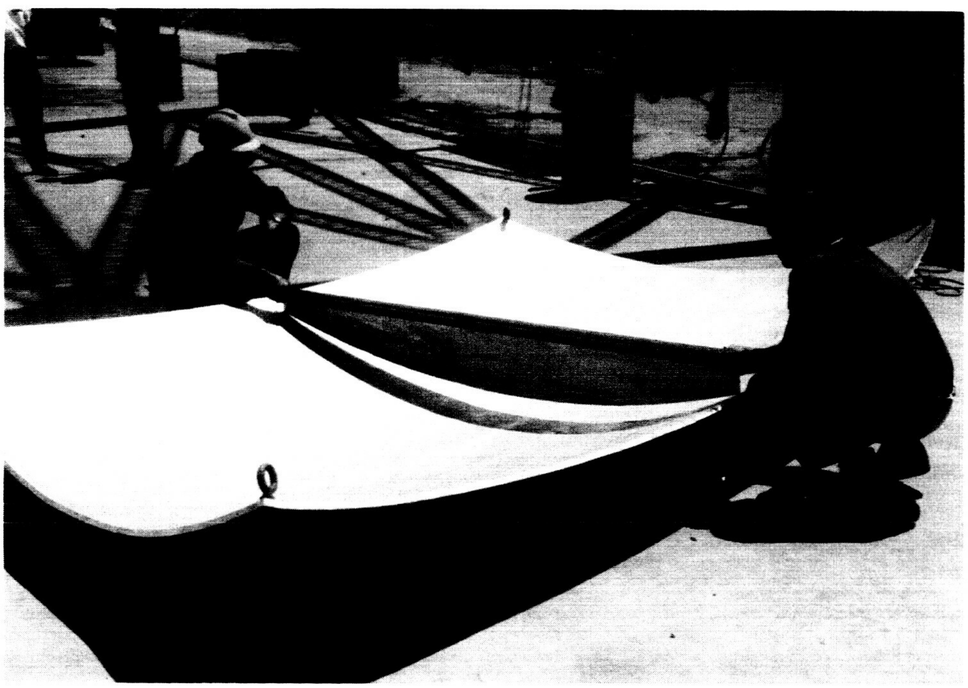


Figure 35 Test No. 7 Base Blank No. 3 Trimmed

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ANALYSIS OF FINAL RESULTS

FORMING

Two general principles were employed to improve forming using the existing apex and base bulkhead gore dies. The first was to balance the elongation along grid lines illustrated in Figure 36. If the die has more elongation along line BE the edge of the material will pull-in more rapidly at B than at A or C, curving the edge. This causes buckling and compressive wrinkles. However, if the elongation is balanced, the draw along each element will be uniform and the edge of the material will remain straight as shown at DEF. Although in these tests the edge was restrained, the balancing was effective in reducing the concentration of loads at the centerlines of each side.

The second tenet is illustrated in Figure 37. If the part could have been formed from a circular blank the part would be self-restrained and a balanced elongation and compression would result. The part then could be trimmed from the blank with minimum distortion due to springback. Furthermore, if the restrain is complete the stresses resolve in tension only if there is enough elongation. Therefore, the clamps were arranged to simulate the restrain provided by the arced beam ABC. Because it was difficult to estimate the effective holding force of the C clamps relative to the stretch press clamps, a balance had not been achieved by the end of the program. A different approach on a die design would be taken on any new project with similar requirements because experience gained from this program showed that the original die design prevented achieving optimum forming conditions. However, the beneficial effect of balanced elongation was proven and the ability of the clamping system to hold heavy materials under explosive forming conditions established.

The grid-type explosive charge pattern (Figure 40) seems to give a uniform pressure without excessive tendency to spike (Figure 41). However, the circular patterns (Figures 16 and 17) appear to be more efficient in terms of forming force per grain of Primacord. The shock waves from the grid seem to cancel each other out in the plane of the charge which may reduce the tendency to spike. Apex Blank No. 2 showed no tendency to spike except where shock waves reflecting from the draw ring could possible be the cause (Figure 41).

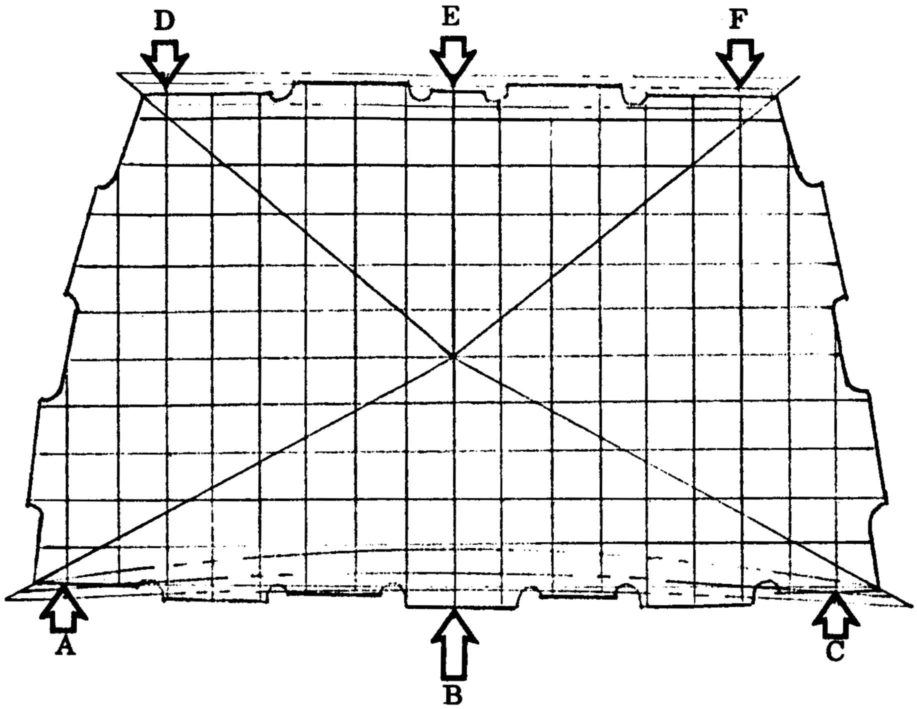

Figure 36 Diagram Illustrating Effect of Balanced Elongation

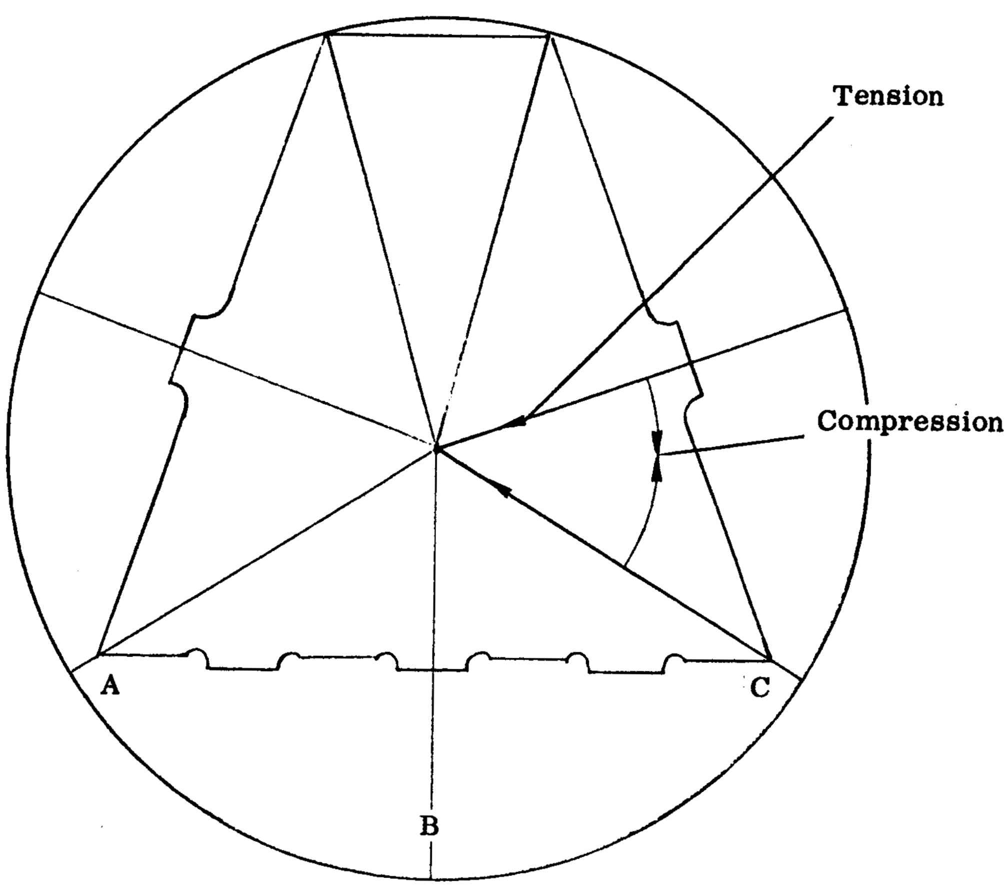

Figure 37 Diagram Illustrating Relationship Between Apex and Circular Blanks

64B080A

Readings taken over 5.000" are accumulated and shown over 10.000" for easy coversion to %

Readings Marked
R = Reversal through
the Sheet Thickness

Upper Readings Taken on Curved Surface, Lower on Outer

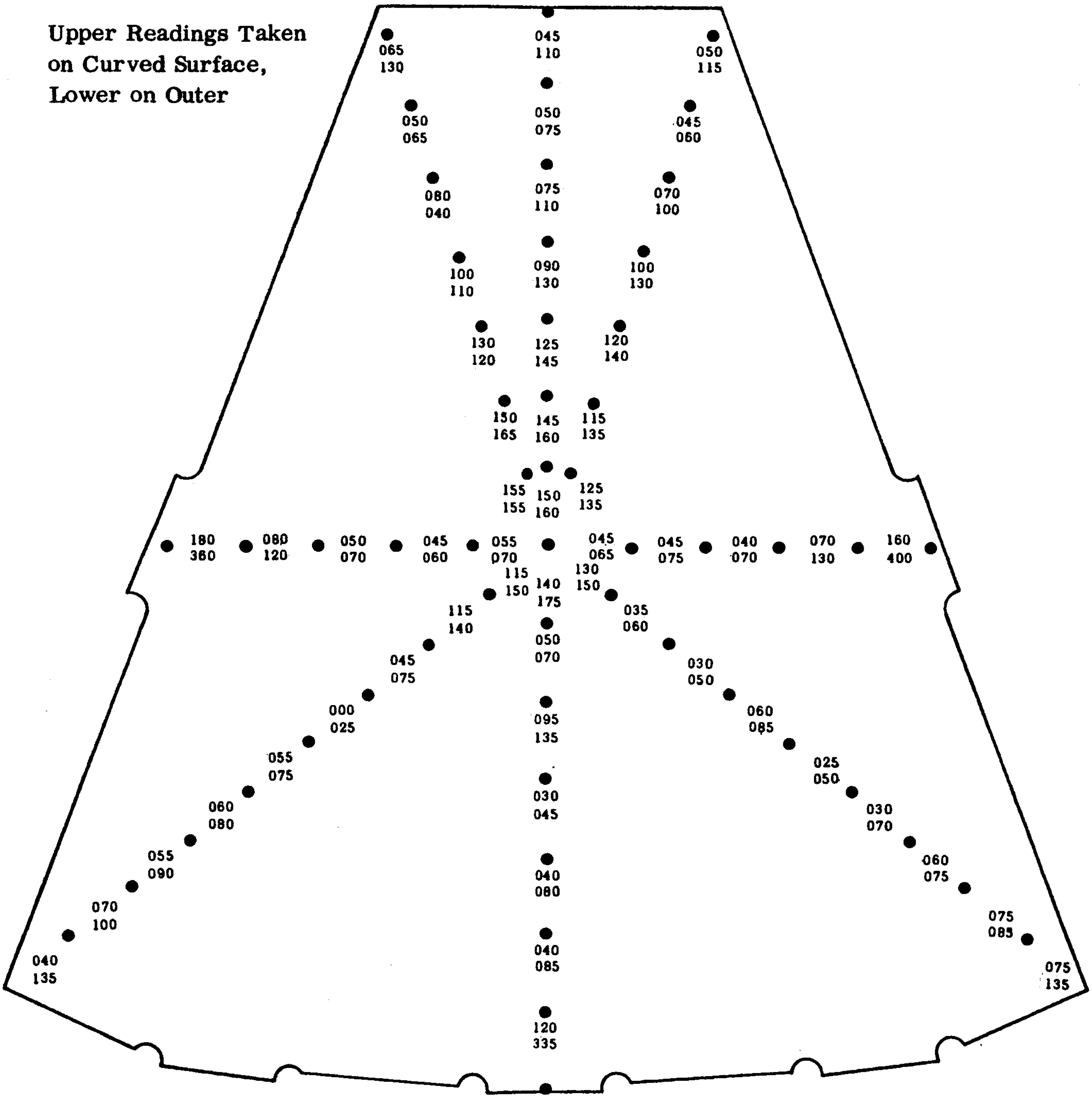

Figure 38 Elongation Reading and Test No. 6, Apex Blank No. 4

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Readings Taken over 5" are Shown Here on 10" centers for Easy Conversion to Percentages

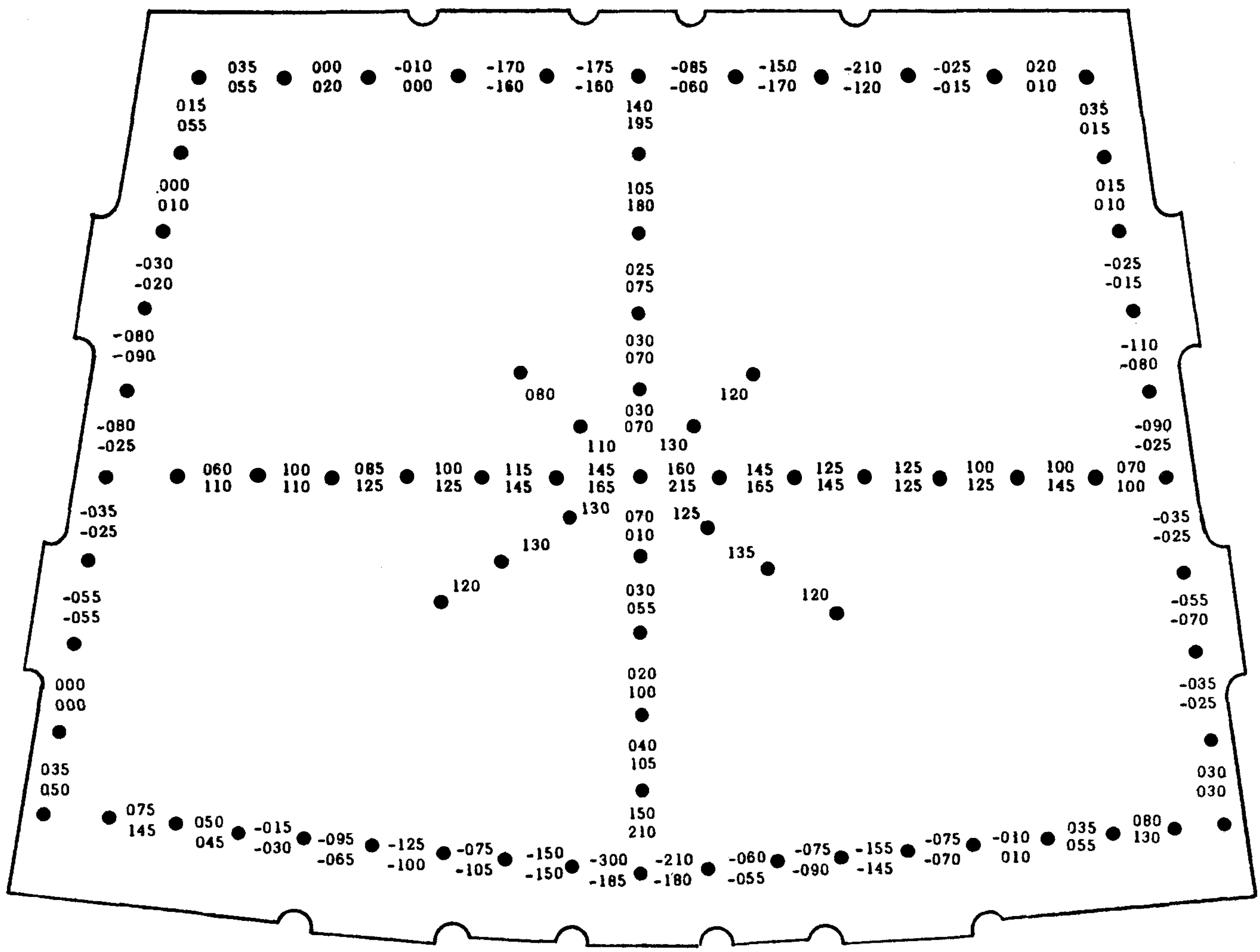


Figure 39 Elongation Test No. 7, Base Blank No. 3

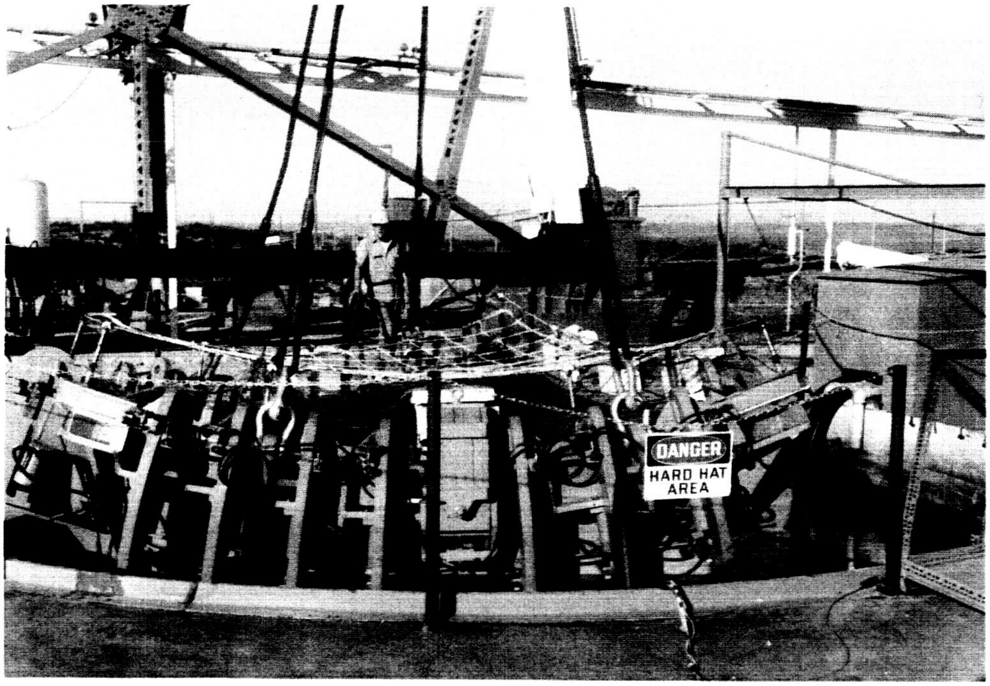


Figure 40 Gridded Type Explosive Charge

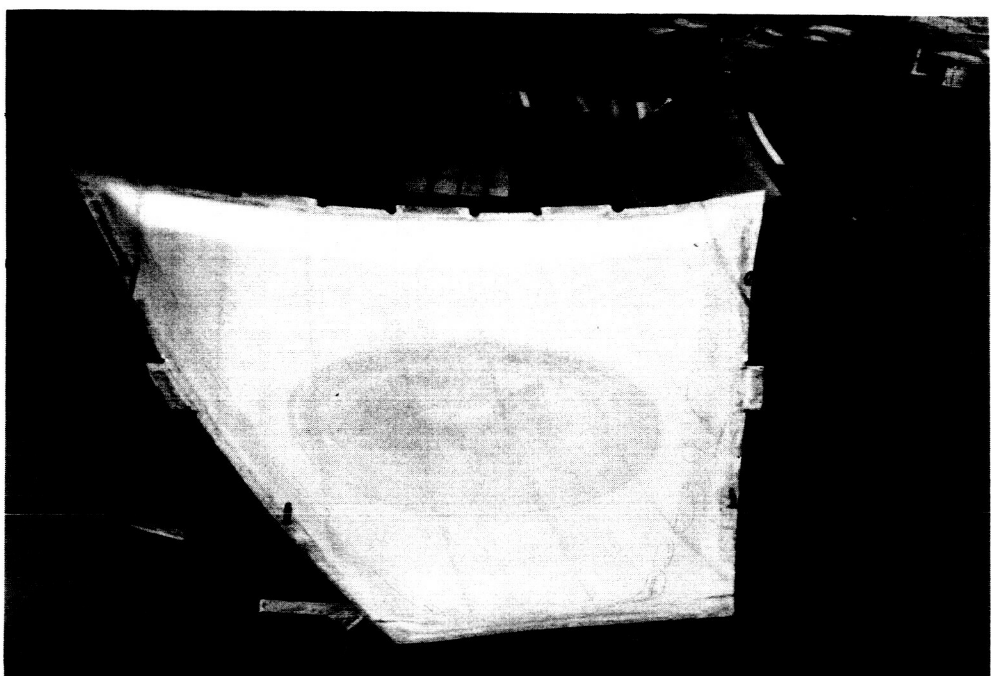


Figure 41 Apex Blank No. 2 Showing Spiking

CONCLUSIONS

Results show that both apex and base gores can be formed over the modified dies. Even though the last parts made were far from print requirements, improvement in the part contour indicates that the following changes would produce parts:

APEX

1. The addition of three stretch press clamps, one at each side and one at the top. The chart (Figure 42) shows that the edge draw-in next to the clamp was 128 percent more than that in the jaws (clamps numbers 1 and 5), while along the bottom it was only 61 percent more. This indicates that the draw ring requires more help from the stretch press clamps. The need for the end clamp is shown by the excessive draw-in in that area (Figure 42).

2. A 150-inch wide blank would eliminate welding and allow us to grip the blank at the corners. This would get away from the compression shown by the side movement of the jaws in clamps numbers 2 and 4.

3. Balance the size of the second shot so that approximately 1 inch of travel remains between the part and the die. This will reduce peening to a minimum.

BASE DIE

1. A plastic pour should be added to the draw ring so that the jack can apply uniform pressure against the serrations.

2. Four additional hydraulic jacks should be located at each corner to increase holding force there.

3. The final shot should form only the last inch of contour to reduce the detrimental effects of both entrapped air and peening.

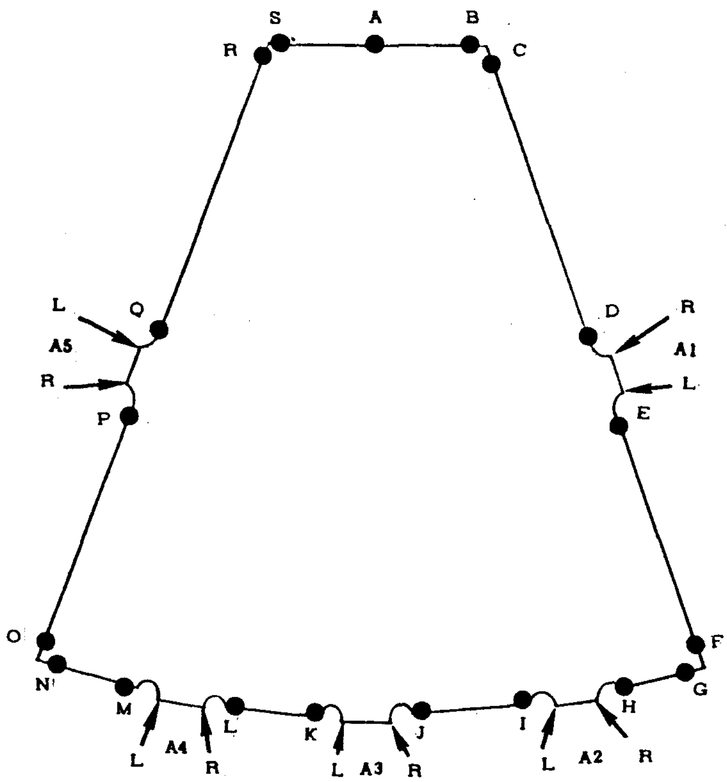
Some provision for springback such as post forming or over-form built into the die would probably be necessary. Due to the tooling, proofing, and production loading time this type of die is not recommended for 2219-T37 as the most economical approach.

The following are some tool design concepts established during this program:

1. The stretch-press type clamp works well under explosive forming conditions and tapers are an excellent mechanical device, however, there is no such thing as a locking taper due to vibration during the forming cycle.

2. Inertia is the prime consideration where moving parts are necessary. They should be as light as possible and plenty of safety factor designed into their restraint.

3. Where gripping is required, the use of coarse serrations at the edge of the part and finer ones on the inside is recommended. In this way the coarse serrations can take a deep grip on the material without causing stress risers for they are protected by the small serrations which in turn do not go deep enough to cause a fracture.



Blank No.	Shot No.	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
	1	.05	.05	.05	.02	.07	.00	.05	.12	.12	.13	.15	.17	.17	.05	.01	.05	.05	.03	.05
1	2	2.7	2.6	1.2	.80	.70	.60	.52	.65	.65	.70	.70	.62	.65	.52	.34	.80	.80	1.0	2.3
	1				.05	.00			1.0	2.0	3.0	2.5	2.5	2.0			.02	.00		
2	1	1.9	1.7	1.0	1.0	.90	.30	.60	.50	.50	.50	.35	.32	.40	.65	.25	.80	1.0	.75	1.8
	2	2.0	1.8	1.0	1.1	1.1	.40	.75	.80	.80	1.0	1.0	.82	.75	.70	.45	1.2	1.2	.85	1.9
	1	.50	.46	.15	.17	.15	.20	.10	.12	.07	.10	.15	.18	.12	.10	.10	.18	.20	.20	.45
	2	2.2	2.0	.80	.97	1.0	.45	.45	.47	.27	.35	.45	.53	.62	.65	.45	1.2	1.1	.85	2.0
3	3	2.2	2.2	.90	1.1	1.2	.60	.80	.65	.42	.50	.65	.65	.77	.68	.50	1.4	1.3	1.0	2.1
	1				.10	.15			.03	.04	.03	.02	.07	.16			.06	.10		
	2				.90	.90			.25	.20	.13	.22	.37	.45			.95	1.0		
	1	.45	.46	.15	.20	.20	.25	.10	.10	.17	.15	.20	.22	.15	.17	.20	.15	.15	.10	.42
	2	1.9	1.6	.70	.90	.92	.55	.43	.40	.47	.53	.60	.67	.65	.60	.68	.95	.15	.70	1.7
4	3	2.1	1.7	.75	.95	1.2	.80	.55	.65	.65	.73	.85	1.0	.95	.10	.65	1.2	1.0	.75	1.8
	1				.20	.05			.13	.20	.35	.45	.25	.16			.02	.18		
					.55	.40			.26	.33	.45	.65	.60	.74			.45	.50		
SLIDE					R	L			R	L	R	L	R	L			R	L		
CLAMP NO.					A1				A2		A3		A4				A5			

Figure 42 Stock Movement During Forming of Apex Blanks

RECOMMENDATIONS

Because the forming of similar parts using 2219-T37 aluminum or other materials with excessive springback may become mandatory, it is unfortunate that this program can not be conclusively finalized. The forming of three more apex, and five more base gores would be required to complete this study.

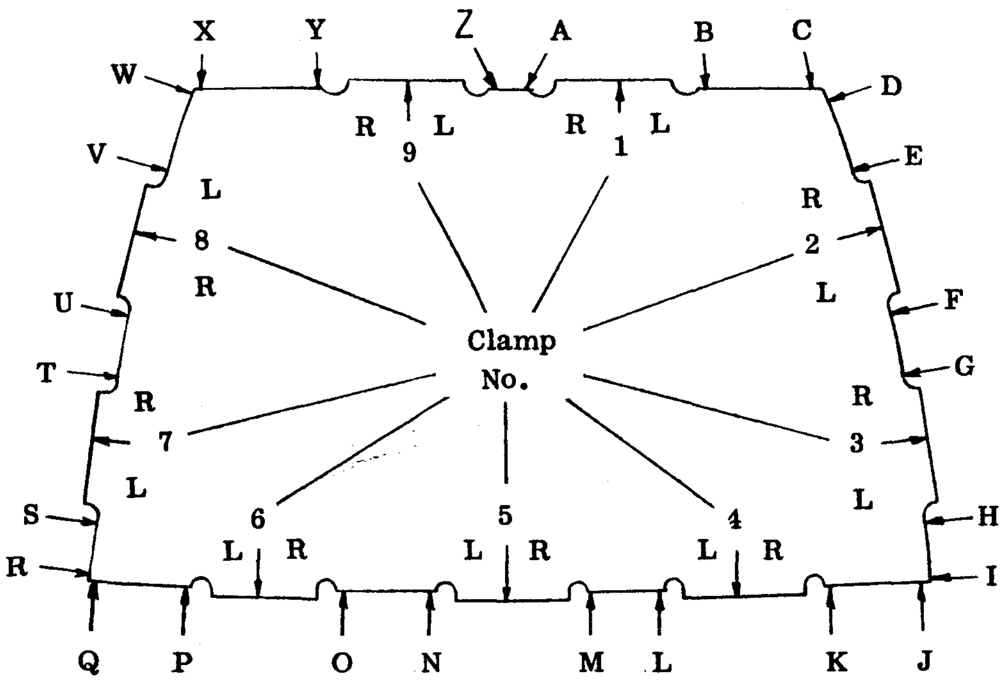
Research and Development work on the following problems should be done to establish Tool Engineering criteria.

1. The effect of peening, due to the part hitting the die, on over-form should be established.

2. The holding effect of shock waves on sections of the part that are already resting against the die while other areas are finished formed should be studied. Preliminary mathematical information, and Test No. 4 of Phase II would indicate that the shock waves would pass through the material into the die with no useful restraining effect long before the holding force would be required to prevent deformation.

3. Observations from Test No. 7 (Figure 43, Shot No. 5) would indicate that a preformed flange around a part can be dynamically energized so that it will impart stretch to the blank rather than just re-forming the radius. Tests should be run to prove or disprove this.

4. Spiking appeared to be caused by the concentration of shock waves primarily due to reflections (Figure 41). Here the spikes were located adjacent to the draw ring and were possibly caused by reflections from it. Work should be done in this area.



Blank No.	Shot No.	Movement Readings in from Zero Point																									
		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
1	1	1.65	1.60	.90	.60	.90	.55	.50	.55	.60	.60	.55	.25	.15	.35	.25	.60	.70	.65	.65	.75	.70	1.20	1.65	1.20	.85	1.80
2	1	.20	.35	.05	.40	.20	.225	.25	.30	.35	.27	.325	.275	.25	.212	.35	.33	.25	.33	.22	.20	.20	.175	.30	.15	.20	.20
	2	2.35	2.25	1.70	2.40	1.90	1.50	1.95	2.60	1.82	1.12	1.72	1.92	1.70	1.56	1.45	1.70	1.35	2.15	2.05	1.50	1.25	1.47	2.15	1.60	2.10	2.35
3	1	.175	.20	.20	.25	.07	.10	.10	.10	.10	.10	.10	.05	.07	.05	.15	.10	.13	.10	.10	.15	.05	.30	.15	.20	.15	.05
	2	1.10	1.40	1.08	1.55	1.10	.80	.90	.90	1.10	.90	1.10	.85	.92	.85	.90	1.10	.65	1.00	.95	.80	.60	1.00	1.10	1.00	1.15	1.10
	3	1.45	1.40	1.43	2.05	1.25	1.20	1.4	2.00	2.60	2.05	2.40	2.95	1.87	2.95	.290	2.70	1.90	2.90	2.15	1.40	1.15	1.40	1.65	1.50	2.00	1.45
	5	1.30	1.35	1.25	1.80	1.05	1.05	1.20	1.70	1.30	1.70	2.15	2.65	1.50	2.70	2.65	2.40	1.55	2.70	2.00	1.20	1.00	1.25	1.45	.135	1.85	1.30
3	1	.125	.10			.025	.025	.025	.00			.08		.025	.025	.10	.08			.05	.03	.05	.05			.10	.15
	2	.55	.50			.275	.35		.30			.48	.55	.375	.375	.60	.58			.30	.43	.50	.25			.60	.50
Clamp No.		R 1	L			R 2	L	R 3	L			R 4	L	R 5	L	R 6	L			R 7	L	R 8	L			R 9	L

Figure 43 Stock Movement During Forming of Base Blanks

APPENDIX

INSTRUMENTATION

INTRODUCTION

The use of instruments was first attempted because of the need for stress data so that planned shots would not fail the tank or dies. There was some question that useful data could be obtained under full scale condition because of interference. The first test was successful enough to indicate that problems could be eliminated. However, because the emphasis of this research program was on forming, shots could not be tailored to instrumentation requirements. Therefore, in general, the high energy measurements made at the Ryan facility are considered inconclusive. Time histories are considered good from the standpoint of timing precision; however, the measurements of the strains, deflections and pressures are useful only as qualitative rather than quantitative values. (Data magnitudes are relative rather than absolute.)

The oscillograms show that dynamic data can be obtained, but that it is difficult to avoid the side effects. The schedule for instrumented shots did not allow for repetitions using the same test configurations, charge standoff and charge weight with the same instrumentation sensors and read-out arrangement.

For the purpose of this report we are briefly outlining the instrumented shots and giving a typical example to show the potential of this type of measurement for future application to full scale projects as well as under laboratory conditions.

EQUIPMENT

The following equipment was used on the first series of measurements. It gives a high frequency response but is limited by the number of readings that can be taken at once:

Tank Wall Strains Only

Three High Frequency Scopes:

1. Tektronix RM-31A High gain amplifier Type L plug.

2. Tektronix 543.

3. Hughes Memo Scope, Model 105, with two Polaroid Scope cameras with mounting attachments.

4. Signal Conditioning:

   Trigger Circuits were:

   (a) Immersed crystal pickup located two to three feet in front of instrumented wall - without time delay circuit. (Propagation time through water used to delay scope sweep for data period.)

   (b) Pressure switch with 1-1/2 volt sweep initiating circuit.

   (c) Squib igniter circuit pulse routed through a Rutherford. Precision Time Delay for sweep triggering.

   (d) Stress Strain sensors:

   Budd metal film 350 ohm strain gauges, temperature compensated for either steel or aluminum as required.

Because more channels were needed, the measurements made during Phase III, the following instrumentation read-out equipment was employed.

High Energy Strains

CEC (Consolidated Electrodynamic Corp.) Recording Oscillograph Model 5-114-P4-18

CEC Fast Galvanometers Type 7-326

CEC Linear Amplifiers Type 1-112

Hewlett-Packard Amplifiers Type 450A

Hydraulic Pressure Switch - Ryan-Fabricated

Signal Conditioning System - Ryan-Fabricated, including:

Quick-disconnect cables for instrument isolation during explosive charge installation.

Squib ignition pulse voltage divider.

System calibration switching.

Capacitor isolation of D.C. ground currents.

Careful shielding of all signals.

EXPLOSIVE FORMING INSTRUMENTATION DYNAMICS

Using the established velocity of acoustic wave in metals such as aluminum and steel at 200, 000 inches per second, we can calculate the signal rise time from the formula:

Transient dynamic strain signal rise

$$e_t = 4 \text{ u sec.}$$

Using 1/2 inch gauge active lengths, we have

$$e_t = 4\ (1/2)\ 10^6 = 2 \text{ u sec.}$$

or 2 u sec. is equal to 1/4 the time period for a full cycle.

Frequency response (period 2 x 4 = 8 u sec.) would be

$$\frac{1u}{8} = 125,000 \text{ cps response}$$

(The above assumes high impedance read-out equipment compared to gauge resistance.) Therefore, oscilloscope read-out will indicate measurements up to this frequency response with no time error from the practical measurement standpoint. However, the oscillograph read-out system is limited by the galvanometer writing rates to less than 1/10 of this frequency without excessive loss in signal magnitude. The main advantage of the oscillograph record is the simultaneous recording of several different signal sources for precise correlation of the data.

TESTS MADE

Instrument measurements were taken on the following tests:

1. Last jury-rig shot on the base die using the scope read-out - three readings were attempted, however, due to radar interference only one was successful.

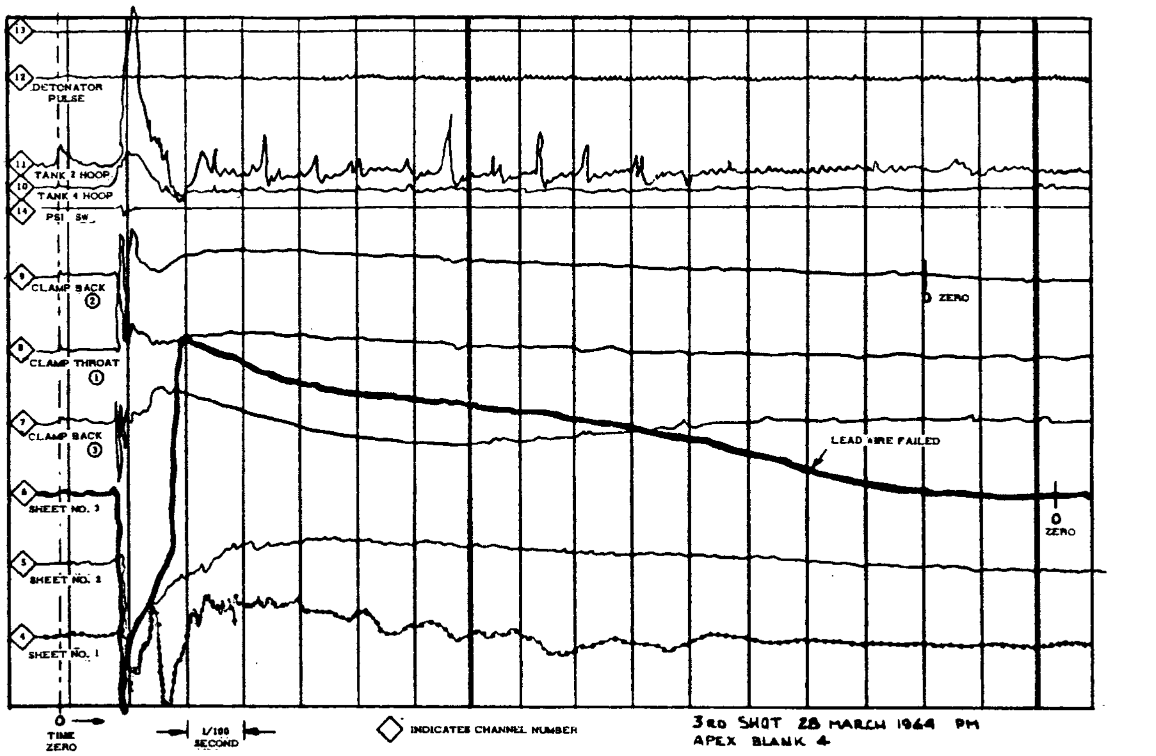
2. Test 1, Apex Blank No. 1, six readings were taken on the tank using a oscillograph recorder and including a squib ignition pulse and pressure switch for time correlation.

3. Test 2, Apex Blank No. 2, two tank hoop readings and four clamp readings.

4. Test 3, Base Blank No. 1, six strain gauges on the die.

5. Test 4, Apex Blank No. 3, two shots were recorded. Four readings on the tank on the first shot. The second shot also included two readings on the clamp.

6. Test 6, Apex Blank No. 4, four gauges on the blank and two on the clamp.



Typical Oscillograph

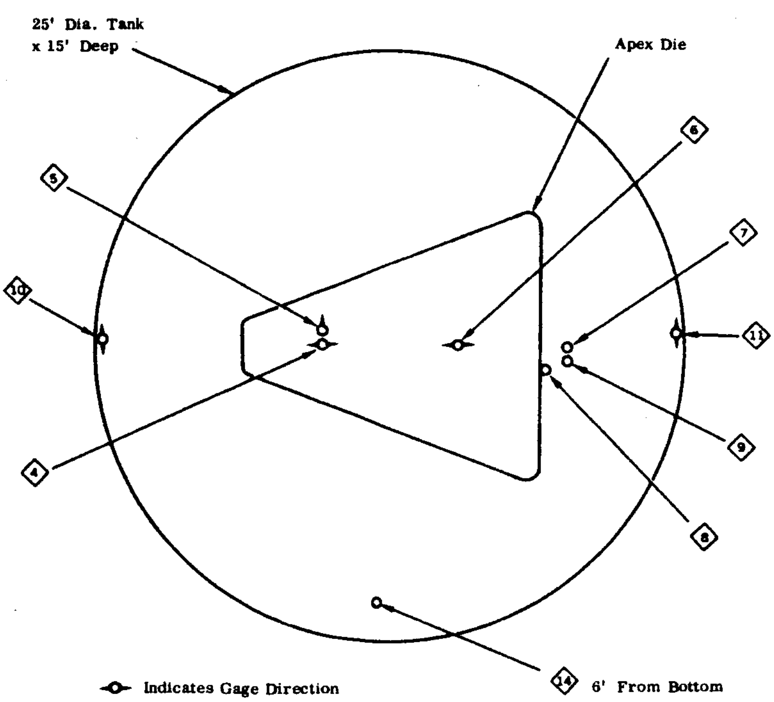


Diagram Showing Location of Gauges for Channels on the Above Oscillograph

DISCUSSION OF RESULTS

Early oscilloscope polaroid photos indicated structural compressive stresses of nearly 40, 000 psi in the heavy steel die. In this case, the initial compressive strains of approximately 1400 microinches per inch were separated in time by about 1/3000 of a second.

Later multichannel oscillographic recordings confirmed the magnitude of the die compressive strains at approximately 1500 microinches per inch starting .008 to .009 seconds after the squib ignition pulse. It is possible that a portion of the initial compressive strain should be attributed to the effect of hydraulic pressure on the surface of the strain gauges. (Poisson effects). The more recent oscillograms taken of clamp strains in clamp areas of tension reactions should also be corrected for this hydraulic pressure effect.

The requirements for changes in sensor location between shots as well as changes in explosive charges made it difficult to adjust signal gains to reasonable trace deflections for accurate measurements. Therefore, there are no confirming oscillograms with gains adjusted to establish precise quantitative values.

Strain gauge data on tank wall, die, and sheet being formed always shows a compression pulse at the beginning of trace deflections. In some installations, tension strains were expected and were actually recorded following the initial compression pulse.

It appears that the hydraulic shock pressure distributed over the surface of the metal film gauges and bonding materials introduce (through Poisson ratio) an initial compressive signal, i.e., lower resistance in the strain sensing element. Once this peak pressure has passed the truemetal strain appears on the recording.

Others have noted this compression effect and have estimated it 5 u"/inch per 100 psi. Thus, a 100, 000 psi shock front would show up as about 500 u"/inch compression for less than 1/1000 second.

Using the CEC oscillographic recording system and fast galvanometers 7-326, have resonant frequencies of 5000 cps; the pressure peak effect is recorded with possibly some overshoot followed by the longer strain data showing actual metal deformations up to 50% of the yield point.

CONCLUSION

As indicated in the discussion under "Results" and shown on the typical oscillogram, it is possible to obtain strain, deflection, and pressure measurements by the use of strain gauge sensors.

Instrumentation systems for use in obtaining high energy data must be carefully designed and calibrated to eliminate unwanted side effects.

A test program plan for instrumented shots must be flexible to take advantage of the data as it is developed, and/or to assure accuracy of measurements by means of repeated shots whenever the values appear questionable.

The original electrical circuiting and oscillograms of all instrumented shots together with signal sensitivity calibrations will be kept on file in the Engineering Department at Ryan for use in case of further interest in this subject.

RECOMMENDATIONS FOR FUTURE INSTRUMENTED HIGH ENERGY MEASUREMENTS

1. Install two or more strain gauges at desired measurement location so that time histories may be taken at two or more writing rates. Thus, the fast sweep can be syncronized to "open up" the time sequence at some interesting portion of the slower sweep covering the entire dynamic envelope.

2. Make enough repetitive shots so that signal gain adjustments can be made for reasonable trace deflections and high accuracy without overshoot.

3. The dynamic calibration of the instrumentation readout system should include strain gauge installations and time history measurements on unstressed metal located adjacent to instrumented structure under dynamic stress. In this way, the "side effects", such as pressure on gauge surface, Poisson ratio, etc., can be isolated from the overall signals in order to arrive at the true strain in the part under consideration.

4. Future instrumented shots should be scheduled so that the data can be analyzed between each group of repetitive measurements in order that corrective action and readout adjustments can be made as early as possible.

5. It seems that a considerable amount of the measurement task could be accomplished by means of small scale tests early in the project. After thus isolating side effects and establishing dynamic calibrations and adequate signal sensors, system isolation and shielding, a few carefully planned full scale shots should yield reliable data on the basic parameters.

6. Once the data has been reduced, consideration should be given to the analysis and interpretation of the results in order to gain detail knowledge of the effect of configuration changes on high energy forming results.

7. It appears that temperature rise in the hydraulic medium should be one of the time history correlation measurements along with pressure, strain, deflection, and source energy.